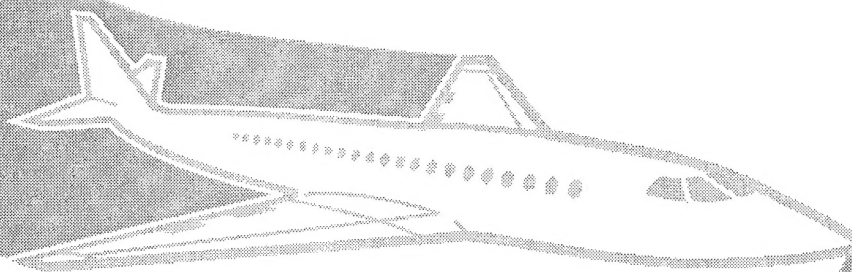


# Approach Station Keeping (ASK) Experiment Plan and Final Report

National Simulation Capability (NSC)  
Experimentation Working Group (EWG)



December 1995

DOT/FAA/CT-TN95/58

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| 16. Abstract<br><br>The Approach Station Keeping (ASK) study was conducted at the request of the Federal Aviation Administration's (FAA's) Flight Standards Organization (AFS-400) to investigate an issue raised by RTCA Special Committee -186 concerning implementation of the proposed Automatic Dependent Surveillance-Broadcast (ADS-B) system. The primary study objective was to investigate whether both Indicated Air Speed (IAS) and Ground Speed (GS) of a leading aircraft were required by the flight crew of a trailing aircraft to maintain separation. The secondary study objective was to investigate whether provision of IAS information of a leading aircraft would enable the flight crew of a trailing aircraft to detect the presence of wind shear. The test bed consisted of the FAA's Reconfigurable Cockpit Simulator (RCS) and General Aviation Trainer (GAT) located at the FAA Technical Center in Atlantic City, NJ. The RCS was configured as a Boeing 747-400 aircraft and flown as the trailing aircraft. The GAT was flown as the leading aircraft at approach and landing speeds corresponding to a Beechcraft Super King Air (BE-20). The dynamic position of the leading aircraft, a data block containing call sign, type aircraft, and GS or GS and IAS of the leading aircraft, and a 3-mile range ring were incorporated in the Navigation Display of the trailing aircraft. Five flight crews conducted 24 approaches each. The wind condition, starting position, configuration and speed, airspeed option, and control mode (autopilot or manual) were varied for each approach. Analysis of subjective and objective data indicated that IAS did not appear to provide an advantage for maintaining instantaneous separation. However, IAS seemed to help pilots as a planning tool for predicting winds, and thereby anticipating the potential loss of separation. The study concluded that the presentation of GS is sufficient to maintain separation, however, if the objective is to identify windshear, IAS is required. |  |  |  |   |  |
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## EXECUTIVE SUMMARY

An RTCA Special Committee (SC-186) was chartered to define the operational and technical requirements for Automatic Dependent Surveillance - Broadcast (ADS-B). Included in their activities was the development of a Minimum Aviation System Performance Standard (MASPS) for ADS-B. The Approach Station Keeping (ASK) study was initiated at the request of the Federal Aviation Administration (FAA) Flight Standards Office (AFS-400) to investigate an issue raised by Working Group 1 of RTCA SC-186 during their meeting of April 6, 1995.

In drafting the surveillance information needs section of the MASPS, some members of the working group suggested that, during the final approach phase of flight, the crew of a trailing aircraft could obtain sufficient information to maintain station behind a leading aircraft if the Ground Speed (GS) of the leading aircraft is electronically presented to the flight crew of the trailing aircraft. Others suggested that both GS and Indicated Airspeed (IAS) must be provided.

The ASK study was conducted to investigate and resolve the airspeed requirements issue. The objectives of the study were to investigate whether IAS information is necessary for maintaining separation, and whether the presence of IAS information enables pilots to detect the presence of a wind shear.

The principal research hypothesis was:

The flight crew of a trailing aircraft will be able to maintain station behind a leading aircraft, on final approach, when the following information is provided to the trailing aircraft:

1. Accurate position information of the leading aircraft.
2. A data block containing aircraft identification, aircraft type, and GS of the leading aircraft.
3. Visual cues that identify the required minimum separation.

The secondary research hypothesis was:

The flight crew of a trailing aircraft will be able to detect the presence of a wind shear when such a phenomenon is acting on the leading aircraft, on final approach, when the following information is provided to the trailing aircraft:

1. Accurate position information of the leading aircraft.
2. A data block containing aircraft identification, aircraft type, GS, and IAS of the leading aircraft.
3. Visual cues that identify the required minimum separation.

The study was conducted under the auspices of the FAA's National Simulation Capability Program during the period July 31 through August 11, 1995. A test bed was established at the FAA Technical Center. The test bed was comprised of the FAA's Reconfigurable Cockpit Simulator (RCS) and General Aviation Trainer (GAT) simulator.

The RCS was configured as a Boeing 747-400 aircraft and flown as the trailing aircraft. The GAT was flown as the leading aircraft at approach and landing speeds corresponding to a Beechcraft Super King Air (BE-20). The Navigation Display of the trailing aircraft was modified to enable presentation of the dynamic position of the leading aircraft and a data block that displayed the call sign, type aircraft, GS, and IAS of the leading aircraft. A 3-nautical mile (NM) arc, coupled to the location of the trailing aircraft, was also added to the Navigation Display to provide a visual range reference to the flight crew. For the purposes of the study, it was assumed that position and data block information was broadcast by the leading aircraft and received by the trailing aircraft using ADS-B technology.

Five two-person flight crews were used as subjects to "fly" the trailing aircraft. All subjects were Airline Transport Pilot-rated. Nine were experienced in operating "glass" cockpit aircraft; one had been trained and had flown glass cockpit simulators. The leading aircraft was flown by two instrument-rated commercial pilots who alternated every three runs.

The study was designed to enable comparison of the spacing achieved by the flight crew of the trailing aircraft when only GS was provided with the spacing achieved when both GS and IAS were provided. Scenarios were structured to present the crew of the trailing aircraft with operational situations that could be faced as they maintain station on an aircraft of much slower approach speed during an Instrument Landing System (ILS) approach to Runway 23L at Raleigh-Durham International Airport (RDU). The flight crew of the trailing aircraft was instructed to maintain as close a position behind the leading aircraft as operationally acceptable to them. In doing so, the flight crew had to maintain not less than 3 NM separation between their aircraft and the leading aircraft when 10 NM or more from the airport and not less than 2.5 NM separation when less than 10 NM from the airport.

The scenarios varied in wind condition, operational condition (position in space, airspeed, and configuration), data block information, and control mode. Each crew flew 24 discrete scenarios. The run order was selected at random to reduce order effects in the data. The run duration was approximately 6 minutes.

Data were collected using four methods. First, the relative positions of both aircraft were recorded each second by the RCS computer. Second, the information on the Navigation and Flight Displays was continuously video recorded, and the interactions of the subjects were continuously recorded on video and audio tape. Third, questionnaires were administered following each run to elicit information regarding the experiences encountered during the run. An additional questionnaire was completed by all subjects at the completion of the final run to elicit opinions regarding the information presented on the Navigation Display and the ASK concept, in general. Fourth, a general discussion was conducted to debrief the subjects at the end of each day. The debriefing sessions were audio recorded.

The test variables used in the analysis were operational conditions (2), wind conditions (3), control modes (2), and data block information presentations (2). The measures used

for the analysis were separation violation occurrence frequency, missed approach frequency, average separation, and separation distance occurrence frequency.

The study found that, statistically, the average separation was not significantly different under both data block display options. This clearly indicates that IAS information is not required to maintain separation. This finding is confirmed by the fact that, except under wind shear conditions, the number of missed approaches and the frequency of separation violations were zero under both display options.

During the debriefing sessions, the pilots indicated that, to maintain separation, they looked at their present separation (distance between the two aircraft), the GS of both aircraft, and the range information (distance from the runway). Based on this information, they made an instantaneous decision whether or not they needed to change their speed.

The study also found that, in scenarios starting with both aircraft at 1800 feet (ft), the pilots seemed to be able to anticipate wind changes and, with the necessary mental calculations, appeared to be able to predict that separation would not be violated. Under the GS-only condition, it appeared that pilots needed to make more speed corrections to maintain the desired separation. In scenarios starting with the leading aircraft at 1800 ft and the trailing aircraft at 4000 ft, when both the GS and IAS of the leading aircraft were provided, the pilots appeared to anticipate that they might close due to wind changes and therefore, made the necessary speed corrections early to avoid the loss of separation.

These findings were validated by the End of Simulation Questionnaires, which indicate that a significantly higher proportion of pilots favored the depiction of IAS information as an option. The questionnaires also indicate that a significantly higher proportion of pilots used IAS information. This finding is further validated by comments made by pilots during debriefing sessions, suggesting that IAS information is useful in identifying wind changes and planning for speed adjustments.

In conclusion, IAS seemed to help pilots as a planning tool for predicting the winds and, thereby, anticipating the potential loss of separation. The availability of IAS enabled them to make the necessary speed changes early in the approach. Use of IAS was particularly advantageous in situations when wind shear was the apparent factor that caused the separation loss potential.

However, IAS did not appear to provide any additional advantage for maintaining an instantaneous separation, implying that GS only is sufficient for maintaining the separation.

In summary, the study showed that, if the objective is to maintain separation, then the presentation of GS is sufficient. If the objective is to identify wind shear, then IAS information is required.

## 1. INTRODUCTION.

The Approach Station Keeping (ASK) study addressed a fundamental issue of flight deck situational awareness (SA). Members of the aviation community suggested that, during the final approach phase of flight, the crew of a trailing aircraft could obtain sufficient information to maintain station behind a leading aircraft if the GS of the leading aircraft is electronically presented to the flight crew of the trailing aircraft. Others recommended that both Ground Speed (GS) and Indicated Airspeed (IAS) must be displayed.

### 1.1 BACKGROUND.

An RTCA Special Committee (SC-186) was chartered to define the operational and technical requirements for Automatic Dependent Surveillance - Broadcast (ADS-B). ADS-B technology is critical to the successful implementation of a number of future operational capabilities including Traffic Collision Avoidance System (TCAS) IV, emerging Free Flight concepts, and the cockpit-based Situational Awareness for Safety (SAS) initiative.

This study addressed an issue raised by Working Group 1 of RTCA SC-186 during their meeting of April 6, 1995. The group questioned pilot SA when operating in a station-keeping mode during final approach. Specifically at question was whether the IAS of a leading aircraft is required by the flight crew of a trailing aircraft to maintain the appropriate separation between both aircraft while on final approach to a common runway.

#### 1.1.1 Problem Statement.

The purpose of this study was to determine whether both GS and IAS of a leading aircraft must be provided to the flight crew of a trailing aircraft to maintain not less than 2.5 nautical miles (NM) between aircraft when operating within 10 NM of the landing runway and 3 NM when operating more than 10 NM from the runway.

The study was designed to compare the spacing achieved by the flight crew of the trailing aircraft when only GS is provided with the spacing achieved when both GS and IAS are provided.

#### 1.1.2 Assumptions.

The following assumptions were incorporated in the design:

- a. Both aircraft are equipped with ADS-B.
- b. Both aircraft can determine their position (latitude, longitude, and altitude) by using the Global Positioning System (GPS) as the navigation data source.
- c. The leading aircraft is capable of broadcasting:

1. Aircraft Identification
2. Aircraft Type
3. GS
4. IAS
5. Position Information

d. The trailing aircraft is capable of receiving the above items and displaying them to the flight crew in a format that enables the flight crew to determine:

1. The range between both aircraft.
2. Changes in forward velocity of the leading aircraft.

e. Air Traffic Control (ATC) services are not provided. That is, for the purpose of the experiment, safe separation would exist at the start of the problem. Flight crews would be instructed that landing clearance would be issued at the appropriate time.

## 1.2 LITERATURE REVIEW.

A variety of documents were reviewed to establish the context for the study approach and experimental design.

Livack (1995a) provided an overview of the issues surrounding the development and implementation of ADS-B with emphasis on requirements definition. He raised a variety of operational, technical, and functional issues related to ADS-B and its role in Traffic Collision Avoidance System (TCAS), Situational Awareness for Safety (SAS), and emerging Free Flight concepts.

Kirkman and Peed (1995) conducted an initial analysis of the surveillance information needs for the ADS-B applications identified by RTCA SC-186. The information is summarized in two categories, i.e., air-to-ground applications and aircraft-to-aircraft applications. Among the identified aircraft-to-aircraft information needs are call sign, type aircraft, GS, horizontal and vertical position, and target altitude. The authors were uncertain whether IAS was also required. This uncertainty was the genesis of the ASK experiment. The authors also included a proposed outline for ADS-B Minimum Aviation System Performance Standards (MASPS).

Livack (1995b) presented three SAS "hardware" systems for use in general aviation (GA) aircraft. He describes a possible integrated SAS computer and display system combination intended for retrofit installation in a typical single or twin-engine GA aircraft. He also discusses the advantages of an SAS system for GA. Attachment II of his paper provides a detailed cost estimate for such an alternative. The author also provided a list of candidate SAS applications in attachment III. This attachment categorizes SAS applications by functions. The functions identified are flight planning and navigation, in-flight collision awareness and avoidance/on-board aircraft surveillance/station keeping, weather awareness and Notices to Airmen (NOTAMs) (via Weatherlink), and other aircraft-related applications. The author also identifies the need for part-task training and lists Air Traffic and Flight Service Station (FSS) applications.

Another article (Initial SAS Applications Selected ..... ) lists eight initial SAS applications. Items are categorized as follows: The SAS Basic System for Validation, SAS Advanced Options for Validation, SAS Air Traffic Validation Tie-In, and SAS Part-Task Training Validation Tie-in.

### 1.3 RESEARCH HYPOTHESES.

Principal and secondary hypotheses were formulated to research the IAS issue.

The principal research hypothesis was:

The flight crew of a trailing aircraft will be able to maintain station behind a leading aircraft, on final approach, when the following information is provided to the trailing aircraft:

1. Accurate position information of the leading aircraft.
2. A data block containing aircraft identification, aircraft type, and GS of the leading aircraft.
3. Visual cues that identify the required minimum separation.

The secondary research hypothesis was:

The flight crew of a trailing aircraft will be able to detect the presence of a wind shear when such a phenomenon is acting on the leading aircraft, on final approach, when the following information is provided to the trailing aircraft:

1. Accurate position information of the leading aircraft.
2. A data block containing aircraft identification, aircraft type, GS, and IAS of the leading aircraft.
3. Visual cues that identify the required minimum separation.

## 2. METHOD.

### 2.1 PARTICIPANTS.

Five 2-person flight crews were used as subjects to "fly" the trailing aircraft. All subjects were Airline Transport Pilot (ATP) rated. Nine were experienced in operating "glass" cockpit aircraft; one had been trained and had flown glass cockpit simulators. The flight crew observer was a glass cockpit pilot.

The leading aircraft was flown by commercial pilots who were instrument-rated. Two pilots alternated every three runs.

### 2.2 INSTRUMENTATION.

#### 2.2.1 Cockpits.

The experiment was conducted at the Federal Aviation Administration (FAA) Technical Center using the Reconfigurable Cockpit Simulator (RCS) located in the Research

Development and Human Factors Laboratory (RDHFL) and the General Aviation Trainer (GAT) located in the Technical and Administration (T&A) Building. The RCS, essentially a generic non-motion simulator, was configured to emulate a Boeing 747-400 aircraft. The RCS was flown as the trailing aircraft. Although configured as a light twin, piston engine aircraft, the GAT was flown using the approach and landing characteristics of a Beechcraft Super King Air (BE-20). The GAT was flown as the leading aircraft.

### 2.2.2 Displays.

Spacing information was provided to the flight crew of the trailing aircraft using the Navigation Display installed in the RCS. The Navigation Display was modified to show the dynamic position, aircraft identification, aircraft type, GS, and IAS of the leading aircraft. A 3-mile range ring, centered on the position of the trailing aircraft, was added to the display. The Navigation Display, as modified, is shown in Figures 1 and 2.

### 2.2.3 Approach Plate.

A Jeppesen approach plate was provided to the flight crews of the leading and trailing aircraft. The approach plate depicted the Instrument Landing System (ILS) approach to Runway 23 Left at Raleigh-Durham International Airport (RDU), Raleigh-Durham, North Carolina.

## 2.3 DESIGN.

### 2.3.1 Sampling Strategy.

Flight crew participation was solicited from the following organizations: Airline Pilots Association (ALPA), Allied Pilots Association (APA), Delta Air Lines (DAL), KIWI International Air Lines (KIWI), Northwest Air Lines Training Corporation (NATCO), Tower Air, Trans World Airlines (TWA), United Air Lines (UAL), and United Parcel Service (UPS). A flyer that requested the participation of interested pilots who were experienced in "glass cockpit" aircraft was forwarded to each organization for posting in an appropriate area. Additionally, participation was elicited from a pool of commercial transport pilots (active and retired) who have made known their interest in supporting the research of advanced concepts.

The subject pilots were randomly selected from the group of individuals who responded. To the extent possible, pilots from the same airline were paired. Assignment as Pilot Flying (PF) or Pilot Not Flying (PNF) was alternated to assure that both pilots had an equal opportunity to exercise control.

#### 2.3.1.1 Operational Conditions.

The experiment incorporated two operational conditions distinguished by the relative altitude, position, IAS, and configuration of the two simulated aircraft at the start of each run. Operational condition parameters are shown in Tables 1 and 2.



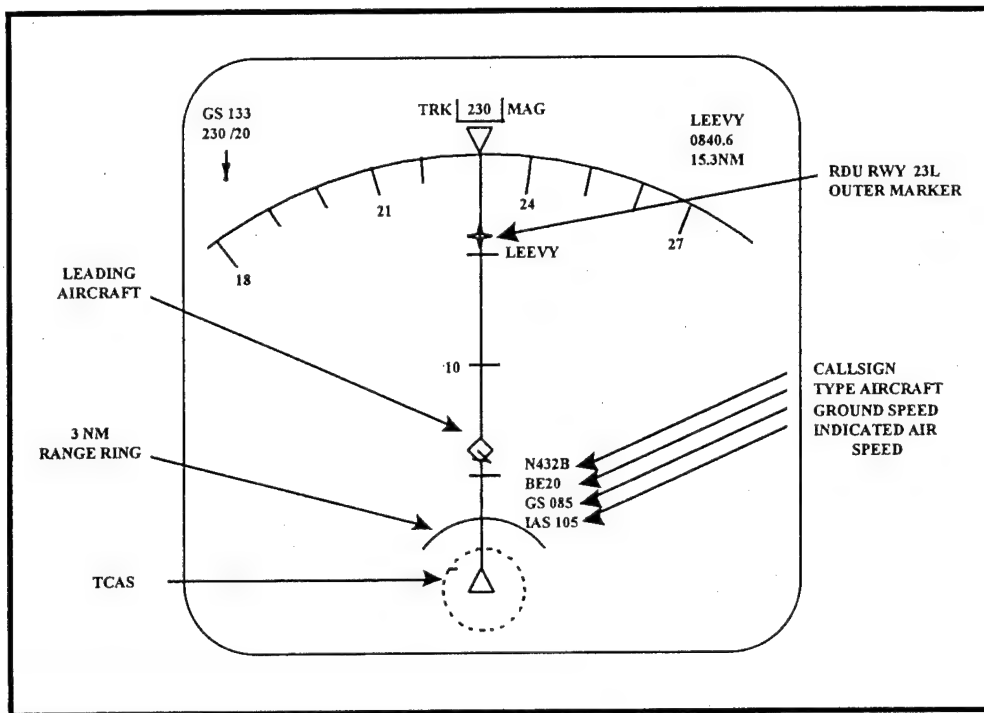


FIGURE 1. NAVIGATION DISPLAY - 20 NM SCALE

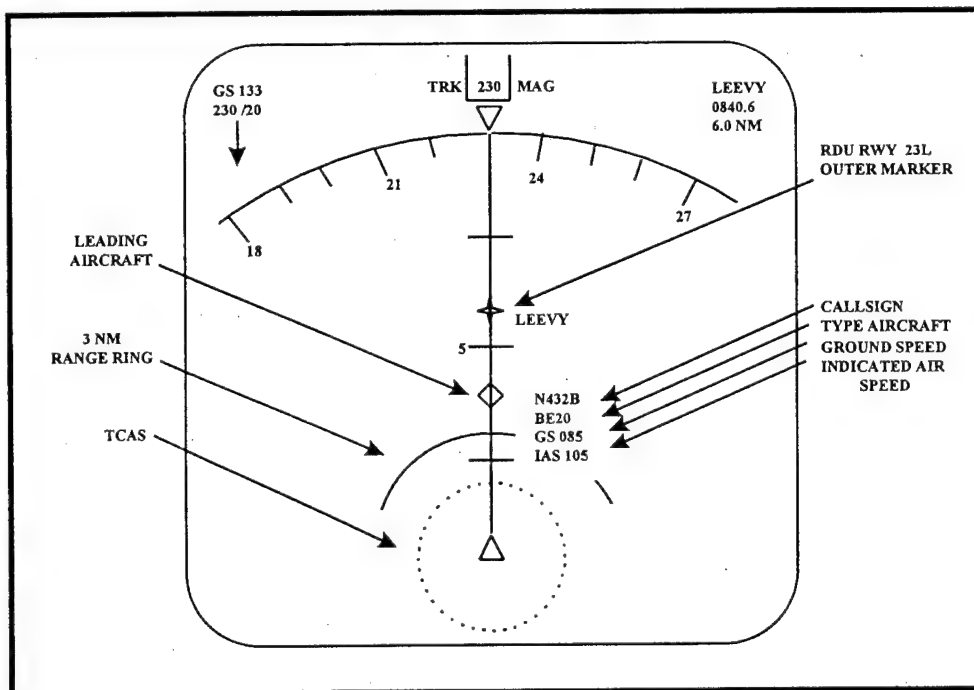


FIGURE 2. NAVIGATION DISPLAY - 10 NM SCALE

TABLE 1. OPERATIONAL CONDITION 1

|                       | LEADING<br>AIRCRAFT      | TRAILING<br>AIRCRAFT     |
|-----------------------|--------------------------|--------------------------|
| POSITION              | RDU 050 RADIAL<br>9 DME* | RDU 050 RADIAL<br>14 DME |
| HEADING               | 230°                     | 230°                     |
| ALTITUDE              | 1800 MSL**               | 1800 MSL                 |
| INDICATED<br>AIRSPEED | 160 KT***                | 200 KT                   |
| FLAPS                 | APPROACH                 | 5°                       |
| GEAR                  | UP                       | UP                       |

\* Distance Measuring Equipment

\*\* Mean Sea Level

\*\*\* Knot

TABLE 2. OPERATIONAL CONDITION 2

|                       | LEADING<br>AIRCRAFT     | TRAILING<br>AIRCRAFT     |
|-----------------------|-------------------------|--------------------------|
| POSITION              | RDU 050 RADIAL<br>9 DME | RDU 050 RADIAL<br>14 DME |
| HEADING               | 230°                    | 230°                     |
| ALTITUDE              | 1800 MSL                | 4000 MSL                 |
| INDICATED<br>AIRSPEED | 160 KT                  | 180 KT                   |
| FLAPS                 | APPROACH                | 10°                      |
| GEAR                  | UP                      | UP                       |

### 2.3.1.2 Wind Conditions.

The experiment incorporated three wind conditions. Condition 1 represented 40 knots (KT) of head wind at 4000 feet (ft) Mean Sea Level (MSL), gradually diminishing to 30 KT at 1800 ft MSL, and to a calm wind on the surface. Condition 2 represented a 50 KT tail wind at 4000 ft MSL, gradually shifting to a 30 KT head wind on the surface. Condition 3 represented a 70 KT head wind at 4000 ft MSL, gradually diminishing to 50 KT at 1800 ft MSL, and to 10 KT on the surface. Wind condition parameters are shown in Table 3.

TABLE 3. WIND CONDITIONS

|                  | SURFACE          |       | 1800 m.s.l.      |       | 4000 m.s.l.      |       |
|------------------|------------------|-------|------------------|-------|------------------|-------|
|                  | DIRECTION        | SPEED | DIRECTION        | SPEED | DIRECTION        | SPEED |
| WIND CONDITION 1 | NA               | 0     | 230 <sup>0</sup> | 30 KT | 230 <sup>0</sup> | 40KT  |
| WIND CONDITION 2 | 230 <sup>0</sup> | 30 KT | 050 <sup>0</sup> | 50 KT | 050 <sup>0</sup> | 50KT  |
| WIND CONDITION 3 | 230 <sup>0</sup> | 10 KT | 230 <sup>0</sup> | 50 KT | 230 <sup>0</sup> | 70 KT |

### 2.3.1.3 Data Block Information.

The experiment incorporated two data block conditions that differed only by the presence or absence of IAS information of the leading aircraft. These were identified as Condition 1 and Condition 2. Subjects were provided with both GS and IAS for 50 percent of the runs and with only GS for the other 50 percent. The two data block variations are shown in Figure 3.

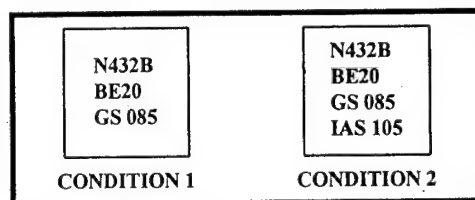


FIGURE 3. DATA BLOCK CONDITIONS

### 2.3.1.4 Control Mode.

Two control modes were exercised and identified as control mode 1 (manual) and control mode 2 (autopilot). An equal number of approaches were flown under each control mode.

### 2.3.2 Procedure.

The experiment was conducted in five 2-day sessions over 10 working days. Two subjects participated during each session. An overview of the sequence of events is provided in Figure 4.

At the start of each data collection run, the two aircraft were positioned on, or on a heading to intercept, the RDU Runway 23L final approach. The aircraft were positioned so that the appropriate separation would exist and could be maintained for approximately

| CREW 1      |              | CREW 1          | CREW 2       | CREW 2          | CREW 3       | CREW 3      |  | CREW 4          | CREW 4       | CREW 4          | CREW 5       | CREW 5          |
|-------------|--------------|-----------------|--------------|-----------------|--------------|-------------|--|-----------------|--------------|-----------------|--------------|-----------------|
|             | JULY 31      | AUGUST 1        | AUGUST 2     | AUGUST 3        | AUGUST 4     |             |  | AUGUST 7        | AUGUST 8     | AUGUST 9        | AUGUST 10    | AUGUST 11       |
| 0800 - 0900 | BRIEFING     | RUNS 10, 11, 12 | BRIEFING     | RUNS 10, 11, 12 | BRIEFING     | 0800 - 0900 |  | RUNS 10, 11, 12 | BRIEFING     | RUNS 10, 11, 12 | BRIEFING     | RUNS 10, 11, 12 |
| 0900 - 0915 | BREAK        | BREAK           | BREAK        | BREAK           | BREAK        | 0900 - 0915 |  | BREAK           | BREAK        | BREAK           | BREAK        | BREAK           |
| 0915 - 1015 | TRAINING     | RUNS 13, 14, 15 | TRAINING     | RUNS 13, 14, 15 | TRAINING     | 0915 - 1015 |  | RUNS 13, 14, 15 | TRAINING     | RUNS 13, 14, 15 | TRAINING     | RUNS 13, 14, 15 |
| 1015 - 1030 | BREAK        | BREAK           | BREAK        | BREAK           | BREAK        | 1015 - 1030 |  | BREAK           | BREAK        | BREAK           | BREAK        | BREAK           |
| 1030 - 1130 | TRAINING     | RUNS 16, 17, 18 | TRAINING     | RUNS 16, 17, 18 | TRAINING     | 1030 - 1130 |  | RUNS 16, 17, 18 | TRAINING     | RUNS 16, 17, 18 | TRAINING     | RUNS 16, 17, 18 |
| 1130 - 1230 | LUNCH        | LUNCH           | LUNCH        | LUNCH           | LUNCH        | 1130 - 1230 |  | LUNCH           | LUNCH        | LUNCH           | LUNCH        | LUNCH           |
| 1230 - 1330 | RUNS 1, 2, 3 | RUNS 19, 20, 21 | RUNS 1, 2, 3 | RUNS 19, 20, 21 | RUNS 1, 2, 3 | 1230 - 1330 |  | RUNS 19, 20, 21 | RUNS 1, 2, 3 | RUNS 19, 20, 21 | RUNS 1, 2, 3 | RUNS 19, 20, 21 |
| 1330 - 1345 | BREAK        | BREAK           | BREAK        | BREAK           | BREAK        | 1330 - 1345 |  | BREAK           | BREAK        | BREAK           | BREAK        | BREAK           |
| 1345 - 1445 | RUNS 4, 5, 6 | RUNS 22, 23, 24 | RUNS 4, 5, 6 | RUNS 22, 23, 24 | RUNS 4, 5, 6 | 1345 - 1445 |  | RUNS 22, 23, 24 | RUNS 4, 5, 6 | RUNS 22, 23, 24 | RUNS 4, 5, 6 | RUNS 22, 23, 24 |
| 1445 - 1500 | BREAK        | BREAK           | BREAK        | BREAK           | BREAK        | 1445 - 1500 |  | BREAK           | BREAK        | BREAK           | BREAK        | BREAK           |
| 1500 - 1600 | RUNS 7, 8, 9 | MAKE UP         | RUNS 7, 8, 9 | MAKE UP         | RUNS 7, 8, 9 | 1500 - 1600 |  | MAKE UP         | RUNS 7, 8, 9 | MAKE UP         | RUNS 7, 8, 9 | MAKE UP         |
| 1600 - 1615 | BREAK        | BREAK           | BREAK        | BREAK           | BREAK        | 1600 - 1615 |  | BREAK           | BREAK        | BREAK           | BREAK        | BREAK           |
| 1615 - 1700 | DEBRIEFING   | DEBRIEFING      | DEBRIEFING   | DEBRIEFING      | DEBRIEFING   | 1615 - 1700 |  | DEBRIEFING      | DEBRIEFING   | DEBRIEFING      | DEBRIEFING   | DEBRIEFING      |

FIGURE 4. SEQUENCE OF EVENTS

90 seconds without flight crew action. Crews were instructed to assume that approach clearance had been received and to execute an RDU ILS Runway 23L approach.

The flight crew of the trailing aircraft was instructed to maintain not less than 3 NM separation between their aircraft and the leading aircraft when 10 NM or more from the airport and not less than 2.5 NM separation when less than 10 NM from the airport. The flight crew of the trailing aircraft was also instructed to fly the aircraft in accordance with Standard Operating Procedures for Boeing 747-400 aircraft.

Crews were cautioned not to utilize practices that are not operationally accepted in the field as a technique to maintain separation (e.g., lowering and then raising the gear to slow and then increase airspeed).

#### 2.3.2.1 Training.

Each session was opened with a one-hour briefing in which the subjects were informed of the objectives of the experiment and their role, therein. An overview of the equipment that would be used was included. The subjects were provided with the Pilot Briefing and Training Handout shown in Appendix A.

Two one-hour training periods in the RCS followed the briefing. The first 30 minutes were devoted to explaining the capabilities of the RCS and to familiarize the subjects with the changes made to the Navigation Display. The remaining 90 minutes were utilized to familiarize the subjects with the location of the various flight instruments and the feel of the RCS controls.

The individual serving as the flight crew observer discussed the various techniques that could be used to successfully set up for both automatic and manually flown approaches. Pilots were then drilled in steep turns (i.e., a 45-degree bank angle while maintaining 280 KT Calibrated Airspeed) to establish and hone their instrument cross check skills. Multiple RDU ILS 23L approaches were then flown; a computer generated target was used in lieu of the GAT. Following the training, each subject agreed that they were suitably prepared to conduct the experiment. Data were not collected during the training periods.

#### 2.3.2.2 Data Collection.

Data were collected using four methods. First, the relative positions of both aircraft were recorded each second by the RCS computer. To aid in analyzing the data, flags were set in the data collection software to identify instances when the 2.5 NM and 3 NM separation test criteria were violated.

Second, the information on the Navigation and Flight Displays were continuously video-recorded, and the interactions of the subjects were continuously recorded on video and audio tape.

Second, the information on the Navigation and Flight Displays were continuously video-recorded, and the interactions of the subjects were continuously recorded on video and audio tape.

Third, questionnaires were used. A questionnaire that elicited demographic and flight experience information for each subject was administered prior to commencing training. A second questionnaire was completed by the PF following each run to elicit information regarding the experiences encountered during the run. A third questionnaire was completed by all subjects at the completion of the final run to elicit opinions regarding the information presented on the Navigation Display and the concept, in general. The flight crew observer also recorded his observations regarding the conduct of each run. The questionnaires that were used are provided in Appendix B.

Finally, a general discussion was conducted to debrief the subjects at the end of each day. The debriefing sessions were audio recorded.

Data collection runs commenced on the afternoon of the first day and continued through the second day until 24 data collection runs were completed for each crew. A 45-minute debriefing was conducted following the completion of each day's data collection activities.

#### 2.3.2.3 Scenarios.

Scenarios were structured to present the crew of the trailing aircraft with operational situations that could be faced as they maintained station on an aircraft of much slower approach speed during an ILS approach to Runway 23L at RDU. The scenarios varied in wind condition, operational condition (position in space, airspeed, and configuration), data block information, and control mode. Scenarios were constructed in the combinations shown in Table 4. The run duration was approximately 6 minutes. Each crew flew 24 discrete scenarios. The run order was selected at random to reduce order effects in the data. The scenario run order by crew is shown in Table 5.

TABLE 4. SCENARIO COMPOSITION

| SCENARIO NUMBER | WIND CONDITION | OPERATIONAL CONDITION | DATA BLOCK INFORMATION | CONTROL MODE |
|-----------------|----------------|-----------------------|------------------------|--------------|
| 1               | W1             | O1                    | D1                     | 1            |
| 2               | W2             | O1                    | D1                     | 1            |
| 3               | W3             | O1                    | D1                     | 1            |
| 4               | W1             | O2                    | D1                     | 1            |
| 5               | W2             | O2                    | D1                     | 1            |
| 6               | W3             | O2                    | D1                     | 1            |

| SCENARIO NUMBER | WIND CONDITION | OPERATIONAL CONDITION | DATA BLOCK INFORMATION | CONTROL MODE |
|-----------------|----------------|-----------------------|------------------------|--------------|
| 7               | W1             | O1                    | D2                     | 1            |
| 8               | W2             | O1                    | D2                     | 1            |
| 9               | W3             | O1                    | D2                     | 1            |
| 10              | W1             | O2                    | D2                     | 1            |
| 11              | W2             | O2                    | D2                     | 1            |
| 12              | W3             | O2                    | D2                     | 1            |

| SCENARIO NUMBER | WIND CONDITION | OPERATIONAL CONDITION | DATA BLOCK INFORMATION | CONTROL MODE |
|-----------------|----------------|-----------------------|------------------------|--------------|
| 13              | W1             | O1                    | D1                     | 2            |
| 14              | W2             | O1                    | D1                     | 2            |
| 15              | W3             | O1                    | D1                     | 2            |
| 16              | W1             | O2                    | D1                     | 2            |
| 17              | W2             | O2                    | D1                     | 2            |
| 18              | W3             | O2                    | D1                     | 2            |

| SCENARIO NUMBER | WIND CONDITION | OPERATIONAL CONDITION | DATA BLOCK INFORMATION | CONTROL MODE |
|-----------------|----------------|-----------------------|------------------------|--------------|
| 19              | W1             | O1                    | D2                     | 2            |
| 20              | W2             | O1                    | D2                     | 2            |
| 21              | W3             | O1                    | D2                     | 2            |
| 22              | W1             | O2                    | D2                     | 2            |
| 23              | W2             | O2                    | D2                     | 2            |
| 24              | W3             | O2                    | D2                     | 2            |

TABLE 5. SCENARIO RUN ORDER

|        | Run 1 | Run 2 | Run 3 | Run 4 | Run 5 | Run 6 | Run 7 | Run 8 | Run 9 | Run 10 | Run 11 | Run 12 | Run 13 | Run 14 | Run 15 | Run 16 | Run 17 | Run 18 | Run 19 | Run 20 | Run 21 | Run 22 | Run 23 | Run 24 |
|--------|-------|-------|-------|-------|-------|-------|-------|-------|-------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Crew 1 | 21    | 8     | 1     | 19    | 4     | 22    | 11    | 15    | 16    | 13     | 2      | 9      | 12     | 3      | 6      | 24     | 5      | 10     | 20     | 23     | 7      | 18     | 17     | 14     |
| Crew 2 | 12    | 8     | 13    | 20    | 4     | 5     | 19    | 15    | 14    | 21     | 3      | 10     | 7      | 11     | 2      | 18     | 1      | 6      | 24     | 16     | 9      | 22     | 17     | 23     |
| Crew 3 | 1     | 2     | 5     | 13    | 18    | 9     | 17    | 24    | 15    | 10     | 4      | 7      | 12     | 6      | 3      | 20     | 23     | 8      | 22     | 19     | 21     | 14     | 11     | 16     |
| Crew 4 | 11    | 7     | 20    | 15    | 17    | 13    | 5     | 10    | 23    | 22     | 9      | 1      | 12     | 6      | 18     | 2      | 8      | 14     | 3      | 16     | 24     | 19     | 4      | 21     |
| Crew 5 | 14    | 4     | 16    | 7     | 13    | 3     | 20    | 9     | 19    | 2      | 6      | 5      | 22     | 12     | 10     | 1      | 23     | 18     | 15     | 24     | 11     | 17     | 8      | 21     |

## 2.4 DATA ANALYSIS.

### 2.4.1 Analysis of Objective Data.

Objective analyses were conducted to enable evaluation of the ability of pilots to maintain station during the approach. Recorded position data were reduced to two major categories, distance between aircraft and missed approach instances. Distance between aircraft data were then grouped into separation interval, average separation, and separation violation sub-categories. In cases where a statistically valid sample was obtained, the data were structured to enable statistical tests to be performed. These tests are described in sections 2.4.1.1, 2.4.1.2, and 2.4.1.3. An overview of this process is shown in Figure 5.

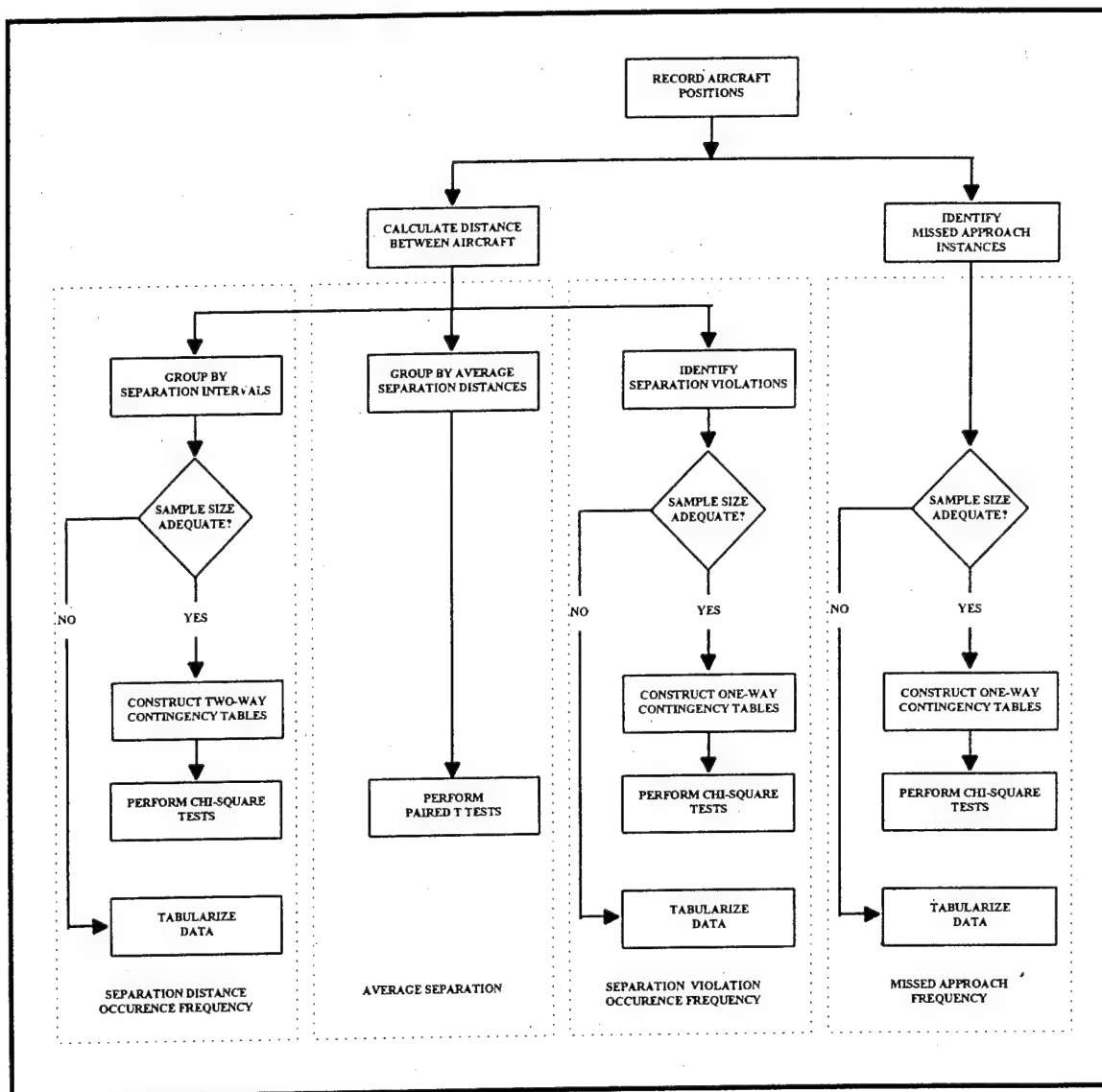


FIGURE 5. ANALYSIS APPROACH OVERVIEW

The test variables used in the analysis were:

1. Operational Conditions (2)
2. Wind Conditions (3)
3. Control Modes (2)
4. Data Block Information Presentations (2)

The measures used for the analysis were:

1. Separation Violation Occurrence Frequency
2. Missed Approach Frequency
3. Average Separation
4. Separation Distance Occurrence Frequency



#### 2.4.1.1 Separation Violation Occurrence Frequency.

Instances where the separation distance between aircraft was less than the required test criteria of 2.5 or 3.0 NM were recorded. A one-way contingency table was constructed for each of the 12 possible combinations of operational condition, wind condition, and control mode shown in Table 6.

TABLE 6. TEST COMBINATIONS

| COMBINATION | WIND<br>CONDITION | OPERATIONAL<br>CONDITION | CONTROL<br>MODE |
|-------------|-------------------|--------------------------|-----------------|
| 1           | 1                 | 1                        | AUTOPILOT       |
| 2           | 2                 | 1                        | AUTOPILOT       |
| 3           | 3                 | 1                        | AUTOPILOT       |
| 4           | 1                 | 1                        | MANUAL          |
| 5           | 2                 | 1                        | MANUAL          |
| 6           | 3                 | 1                        | MANUAL          |
| 7           | 1                 | 2                        | AUTOPILOT       |
| 8           | 2                 | 2                        | AUTOPILOT       |
| 9           | 3                 | 2                        | AUTOPILOT       |
| 10          | 1                 | 2                        | MANUAL          |
| 11          | 2                 | 2                        | MANUAL          |
| 12          | 3                 | 2                        | MANUAL          |

These data were then reviewed to determine the presence of a statistically valid sample. If a statistically valid sample was obtained, Chi-square tests were performed. See Figure 6.

| SPEED<br>INFORMATION                  | NUMBER OF<br>SEPARATION<br>VIOLATIONS |
|---------------------------------------|---------------------------------------|
| GROUND SPEED                          | $f_{11}$                              |
| GROUND SPEED &<br>INDICATED AIR SPEED | $f_{21}$                              |

$f_{11}, f_{21}$  = frequency of occurrence

FIGURE 6. ONE-WAY CONTINGENCY TABLE  
EXAMPLE - SEPARATION VIOLATIONS

#### 2.4.1.2 Missed Approach Frequency.

Instances where the pilot executed a missed approach to avoid violation of the separation test criteria were recorded. A one-way contingency table was constructed for each of the 12 possible combinations of operational condition, wind condition, and control mode. These data were then reviewed to determine the presence of a statistically valid sample. If a statistically valid sample was obtained, Chi-square tests were performed. See Figure 7.

| SPEED<br>INFORMATION                  | NUMBER OF<br>MISSED<br>APPROACHES |
|---------------------------------------|-----------------------------------|
| GROUND SPEED                          | $f_{11}$                          |
| GROUND SPEED &<br>INDICATED AIR SPEED | $f_{21}$                          |

$f_{11}, f_{21}$  = frequency of occurrence

FIGURE 7. ONE-WAY CONTINGENCY TABLE EXAMPLE - MISSED APPROACHES

#### 2.4.1.3 Average Separation.

An equal number of runs were conducted using D1 (i.e., GS only) and D2 (i.e., GS and IAS). Paired t-tests were used to compare the average separation between the two data block options. Average separation for each of the 24 scenarios, previously identified in Table 4, was computed as an arithmetic mean. The average separations under D1 and D2 were then paired for each crew. Twelve paired t-tests were performed corresponding to each combination of wind condition, operational condition, and control mode. The 12 test combinations are shown in Table 6.

#### 2.4.1.4 Separation Distance Occurrence Frequency.

The relative positions of both aircraft were recorded each second enabling the separation distance between aircraft to be calculated for each second. The separation distances were then grouped by intervals to produce a frequency count for each interval. A two-way contingency table was then constructed for each of the 12 possible combinations shown in Table 6. Because the collected data were frequency counts (a non-normal distribution), Chi-square tests were performed for each distance interval group. An example is shown in Figure 8.

| SEPARATION<br>SPEED<br>INFORMATIO     | 1.5 - 2.5 | 2.5 - 3.5 | 3.5- 4.5 | 4.5- 5.5 | > 5.5    |
|---------------------------------------|-----------|-----------|----------|----------|----------|
| GROUND SPEED                          | $f_{11}$  | $f_{12}$  | $f_{13}$ | $f_{14}$ | $f_{15}$ |
| GROUND SPEED &<br>INDICATED AIR SPEED | $f_{21}$  | $f_{22}$  | $f_{23}$ | $f_{24}$ | $f_{25}$ |

$f_1, f_{25}$  = frequency of occurrence

FIGURE 8. 2-WAY CONTINGENCY TABLE EXAMPLE

### 2.4.2 Analysis Of Subjective Data.

Subjective data were obtained through questionnaires and debriefing session discussions. The questionnaires were designed to elicit responses in three forms, i.e., yes/no, multiple choice, and subject comments. Yes/No and multiple choice questions were analyzed using the Binomial distribution for population proportion. In the multiple choice case, responses were reduced into two categories, i.e., GS Only and Some Preference for IAS.

Subject comments were reviewed for meaning, grouped, counted, and reported. A statistical analysis was not performed on subject comments data.

### 3. SCHEDULE.

Timelines of major experiment activities are provided in Figure 9. A 27-working day shakedown period during July was used to validate the scenarios and to ensure test bed fidelity. A 10-working day data collection period commenced on July 31 and ended on August 11, 1995. Data reduction and analysis activities were conducted over a 20-working day period. Initial findings were made available on August 28, 1995. The draft report was developed over a 20-working day period and submitted for management review. The final report was completed on October 20, 1995 and submitted for editing and publication.

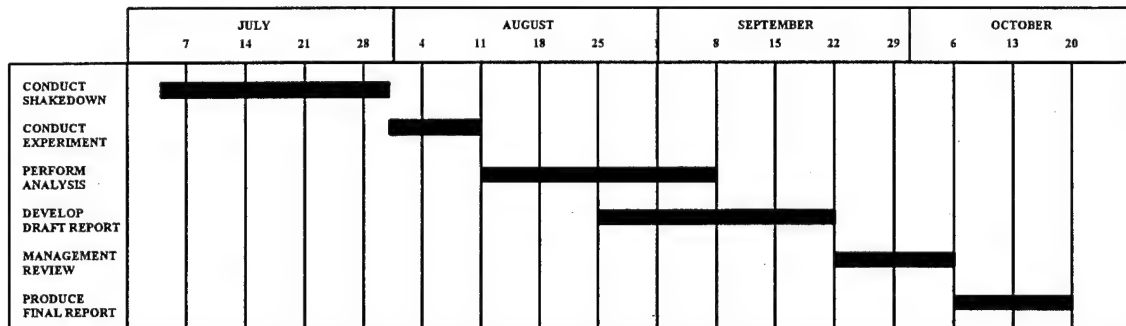


FIGURE 9. EXPERIMENT SCHEDULE

#### 4. RESULTS.

##### 4.1 FREQUENCY OF VIOLATION EVENTS.

The frequency of violations for the different conditions are summarized in Table 7. All separation violations occurred when operating in wind condition 2. These data infer that it was more difficult to maintain separation when a tail wind was present at altitude and a head wind was present on the surface.

Statistical analyses were not performed since the sample size in each of the cells was too small, and, in many cases, it was zero.

TABLE 7. FREQUENCY OF VIOLATION EVENTS

| Condition                             | Autopilot |        |        | Manual |        |        |
|---------------------------------------|-----------|--------|--------|--------|--------|--------|
|                                       | Wind 1    | Wind 2 | Wind 3 | Wind 1 | Wind 2 | Wind 3 |
| Operating Condition 1<br>(GS only)    | 0         | 0      | 0      | 0      | 1      | 0      |
| Operating Condition 1<br>(GS and IAS) | 0         | 0      | 0      | 0      | 3      | 0      |
| Operating Condition 2<br>(GS only)    | 0         | 3      | 0      | 0      | 4      | 0      |
| Operating Condition 2<br>(GS and IAS) | 0         | 2      | 0      | 0      | 4      | 0      |

##### 4.2 FREQUENCY OF MISSED APPROACH EVENTS.

The frequency of missed approach events for the different conditions are summarized in Table 8. All missed approaches occurred when operating in wind condition 2. These data again infer that it was more difficult to maintain separation under wind condition 2 as compared to the head winds present in wind conditions 1 and 3.

Statistical analyses were not performed since the sample size in each of the cells was too small, and, in many cases, it was zero.

TABLE 8. FREQUENCY OF MISSED APPROACH EVENTS

| Condition                             | Autopilot |        |        | Manual |        |        |
|---------------------------------------|-----------|--------|--------|--------|--------|--------|
|                                       | Wind 1    | Wind 2 | Wind 3 | Wind 1 | Wind 2 | Wind 3 |
| Operating Condition 1<br>(GS only)    | 0         | 0      | 0      | 0      | 1      | 0      |
| Operating Condition 1<br>(GS and IAS) | 0         | 0      | 0      | 0      | 1      | 0      |
| Operating Condition 2<br>(GS only)    | 0         | 4      | 0      | 0      | 4      | 0      |
| Operating Condition 2<br>(GS and IAS) | 0         | 2      | 0      | 0      | 3      | 0      |

#### 4.3 COMPARISON OF AVERAGE SEPARATION.

Twelve separate paired t-tests were conducted to investigate whether the addition of the IAS information affected the average separation. The null hypothesis for each of these tests was: "There is no difference in average separation under the GS only and the GS and IAS options." The alternate hypothesis was: "There is a difference in average separation under the GS only and the GS and IAS options." The average separation was computed for each scenario and for each crew. The results of these tests revealed that there was not a significant difference in the average separations under the GS only and the GS and IAS options for any of the test combinations. The results of these tests are summarized in Table 9.

The test results are significant if the p-value is less than or equal to the type I error probability (i.e.,  $\alpha = 0.05$ ).

#### 4.4 COMPARISON OF SEPARATION DISTRIBUTION.

Paired t-tests, alone, did not enable determination of how long pilots were able to maintain separation in any given range (e.g., 3 to 4 NM, 4 to 5 NM). The average separation results produced by the t-tests for any given data set could be statistically not different as for any other data set, but the distribution of separation frequency could be statistically different. It was, therefore, important to examine whether pilots could maintain higher separation for a longer time under either display option (as implied by a higher proportion of counts).

TABLE 9. SUMMARY OF PAIRED T-TEST RESULTS

| Wind Condition | Operating Condition | Control Mode | Result  |
|----------------|---------------------|--------------|---|
| 1              | 1                   | Autopilot    | T= -0.633, df = 4, p = 0.5606,<br>Result: Not Significant |
| 2              | 1                   | Autopilot    | T= 0.416, df = 4, p = 0.6982<br>Result: Not Significant   |
| 3              | 1                   | Autopilot    | T= -1.297, df = 4, p = 0.2641<br>Result: Not Significant  |
| 1              | 1                   | Manual       | T= -0.2532, df = 4, p = 0.5606<br>Result: Not Significant |
| 2              | 1                   | Manual       | T= 0.2369, df = 4, p = 0.4555<br>Result: Not Significant  |
| 3              | 1                   | Manual       | T= -1.8380, df = 4, p = 0.1399<br>Result: Not Significant |
| 1              | 2                   | Autopilot    | T= 2.7764, df = 4, p = 0.6789<br>Result: Not Significant  |
| 2              | 2                   | Autopilot    | T= -1.9222, df = 4, p = 0.1269<br>Result: Not Significant |
| 3              | 2                   | Autopilot    | T= -0.6226, df = 4, p= 0.5674<br>Result: Not Significant  |
| 1              | 2                   | Manual       | T= 1.6333, df = 4, p= 0.1777<br>Result: Not Significant   |
| 2              | 2                   | Manual       | T= -1.2216, df = 4, p = 0.2889<br>Result: Not Significant |
| 3              | 2                   | Manual       | T= 0.0712, df = 4, p = 0.9466<br>Result: Not Significant  |

where - T is the t statistic test value as computed,  
df is the degrees of freedom, and  
p is the probability value based on the computed T value.

To examine whether the proportion of observations for different separation ranges were the same under both display options, 2-way contingency table tests were used with Chi-square as the test statistic.

The null hypothesis was: "The proportion of observations falling into different separation ranges is the same whether or not IAS information was provided." The alternate hypothesis was: "The proportion of observations falling into different separation ranges *is* not the same whether or not IAS information was provided." Results are provided in the sections that follow.

#### 4.4.1 Analysis of Separation Distributions for Operational Condition 1.

The results of the 2-way contingency table, Chi-square tests for operational condition 1 are summarized in Table 10. The results of these tests indicated that the null hypothesis was not supported for all test combinations. Figures were then plotted for both speed information options in order to investigate the relationship between these proportions and the separation intervals.

##### 4.4.1.1 Wind Condition 1 (Headwind).

Figures 10 and 11 show that the minimum separation for operational condition 1 occurred in the 3.5 to 4.5 NM separation interval. Because the trailing aircraft always had head winds that were equal to or stronger than those affecting the leading aircraft, and both range and GS information were available, separation should have been relatively easy to maintain. Since the violation potential was minimal, it appears that the presence or absence of IAS had little or no effect on maintaining separation. However, pilots seemed to have slowed down earlier when IAS was provided, apparently recognizing that a head wind was acting on the leading aircraft. This is observed by a higher proportion of observations under the 4.5-5.5 NM range as compared to when only GS was provided.

This may imply that pilots could plan their approach more cautiously with IAS information. This implication may have utility when more than two aircraft are lined up in a queue for the final approach (i.e., the domino effect). With the help of IAS (and therefore wind information acting on the leading aircraft), pilots may be able to determine the approach speeds more effectively, thereby reducing the domino effect.

Interestingly, the graphs for autopilot and manual modes show different slopes for the relationship of proportion of observations and separation interval. This may be because operating the simulator in the manual mode is more difficult than operating in the autopilot mode. The pilots may have attended to activities other than concentrating on separation.

TABLE 10. SUMMARY OF 2-WAY CONTINGENCY TABLE CHI-SQUARE TESTS  
(OPERATIONAL CONDITION 1)

| Wind Condition | Operating Condition | Control Mode | Result   |
|----------------|---------------------|--------------|--|
| 1              | 1                   | Autopilot    | Chi-square test statistic = 90.48<br>df = 1, $\alpha$ = 0.05<br>Chi-square reference value = 3.843<br>Result: Significant  |
| 1              | 1                   | Manual       | Chi-square test statistic = 53.24<br>df = 1, $\alpha$ = 0.05<br>Chi-square reference value = 3.843<br>Result: Significant  |
| 2              | 1                   | Autopilot    | Chi-square test statistic = 73.87<br>df = 2, $\alpha$ = 0.05<br>Chi-square reference value = 5.992<br>Result: Significant  |
| 2              | 1                   | Manual       | Chi-square test statistic = 70.40<br>df = 3, $\alpha$ = 0.05<br>Chi-square reference value = 7.815<br>Result: Significant  |
| 3              | 1                   | Autopilot    | Chi-square test statistic = 18.58<br>df = 2, $\alpha$ = 0.05<br>Chi-square reference value = 5.992<br>Result: Significant  |
| 3              | 1                   | Manual       | Chi-square test statistic = 12.687<br>df = 1, $\alpha$ = 0.05<br>Chi-square reference value = 3.843<br>Result: Significant |

where - Chi-square test statistic is a computed value,  
df is the degrees of freedom,  
Chi-square reference value is based on the true Chi-square distribution for  
the corresponding degrees of freedom, and  
 $\alpha$  is the type I error probability.



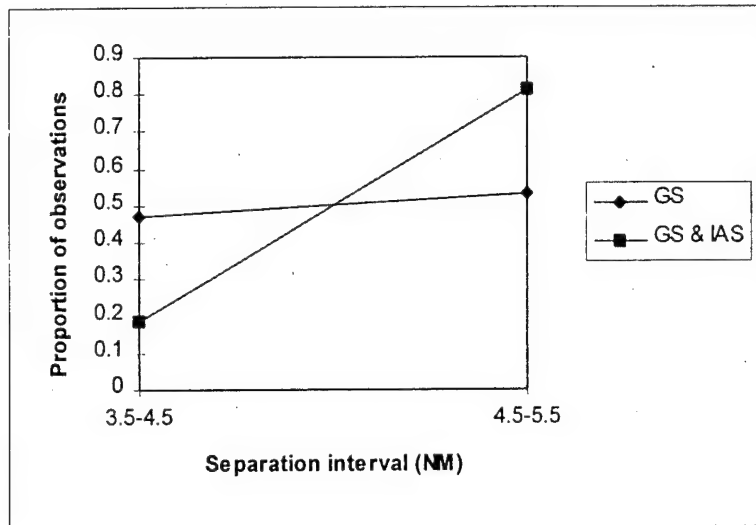


FIGURE 10. PROPORTION OF OBSERVATIONS UNDER SEPARATION INTERVAL (OPERATIONAL CONDITION 1, WIND 1, AUTOPILOT MODE)

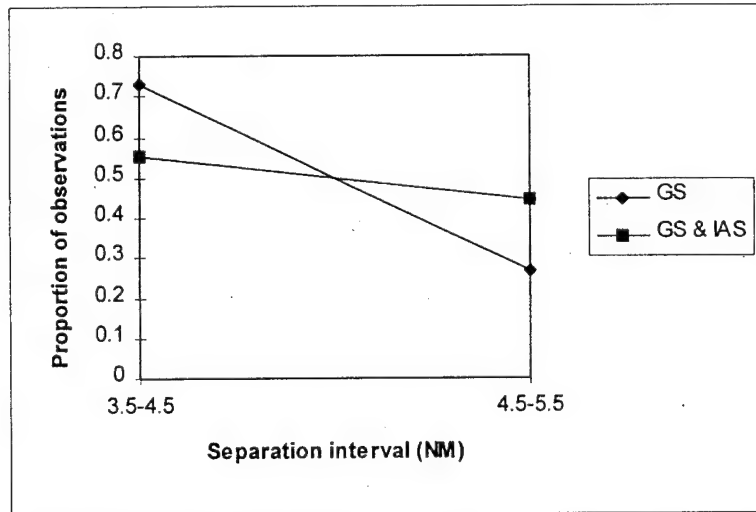


FIGURE 11. PROPORTION OF OBSERVATIONS UNDER SEPARATION INTERVAL (OPERATIONAL CONDITION 1, WIND 1, MANUAL MODE)

#### 4.4.1.2 Wind Condition 2 (Wind Shear).

As shown in Figures 12 and 13, under the GS only option, a higher proportion of observations were obtained in the 3.5 to 4.5 NM separation interval than when both GS and IAS were provided. This may have occurred because the pilots of the trailing aircraft anticipated wind changes and (with necessary mental calculations) predicted that separation would not be violated. They, therefore, may not have felt it necessary to make speed corrections to maintain separation. Conversely, under the GS only option, pilots made speed corrections to maintain their separation, not knowing the wind characteristics that were affecting the leading aircraft.

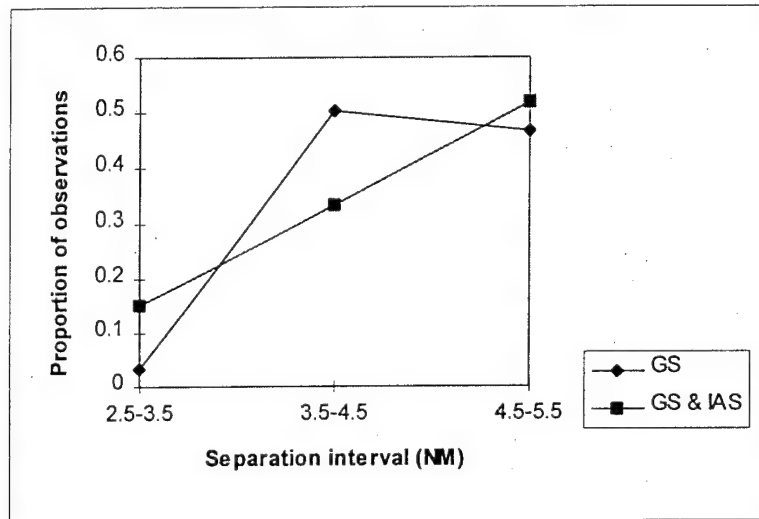


FIGURE 12. PROPORTION OF OBSERVATIONS UNDER SEPARATION INTERVAL (OPERATIONAL CONDITION 1, WIND 2, AUTOPILOT MODE)

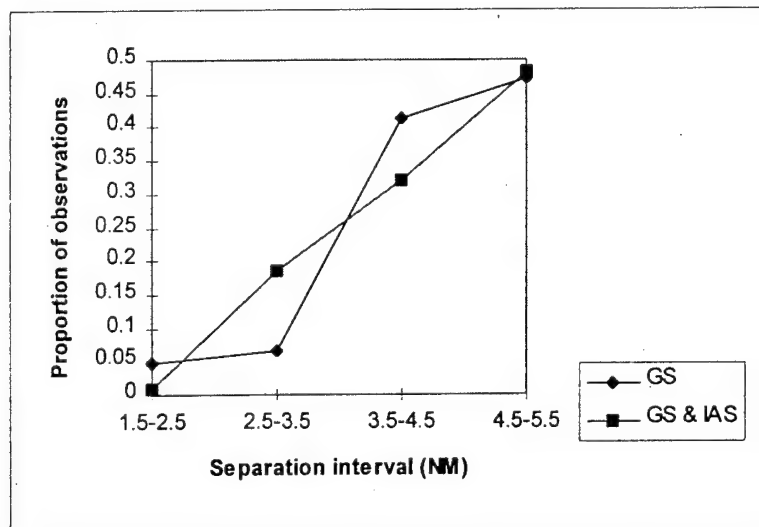


FIGURE 13. PROPORTION OF OBSERVATIONS UNDER SEPARATION INTERVAL (OPERATIONAL CONDITION 1, WIND 2, MANUAL MODE)

Figure 13 shows a small proportion of observations in the 1.5 to 2.5 NM separation interval. A similar result is not present under the autopilot mode and therefore could be attributed to the manual flying operation. The effect of manual flying, which requires more attention in manipulating the flight controls than does the autopilot mode, in addition to the wind effects, may have caused the separation violations. Both Figures 12 and 13, however, show the same trend under the two display options, confirming the wind anticipation rationale described in the preceding paragraph.

#### 4.4.1.3 Wind Condition 3 (Strong Headwind).

The trends shown in Figure 14 indicate a similar proportion of observations at each range for both display options. Wind condition 3 produced a strong head wind component affecting both aircraft. However, as the aircraft descended, the wind speed decreased, thus increasing the separation between the aircraft. Throughout the approach, the wind affecting the trailing aircraft was always equal to, or more than, that affecting the leading aircraft. Additionally, the aircraft were initially separated by 5.4 NM. Since there was always more than adequate separation present, the presentation of IAS information likely did not affect pilot speed control behavior. They apparently were able to determine that adequate separation would exist throughout the flight. As shown in Figure 14, the minimum separation interval was in the range of 3.5 to 4.5 NM, further confirming this observation.

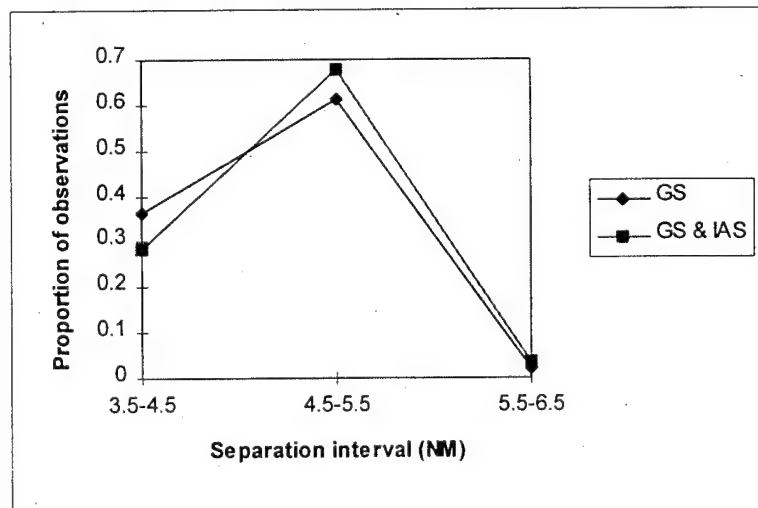


FIGURE 14. PROPORTION OF OBSERVATIONS UNDER SEPARATION INTERVAL (OPERATIONAL CONDITION 1, WIND 3, AUTOPILOT MODE)

As shown in Figure 15, the wind condition 3, autopilot mode demonstrates the same trends present in the manual mode. Since there was always more than adequate separation present, the presentation of IAS information likely did not affect pilot speed control behavior. The minimum separation interval was in the 3.0 to 4.0 NM range.

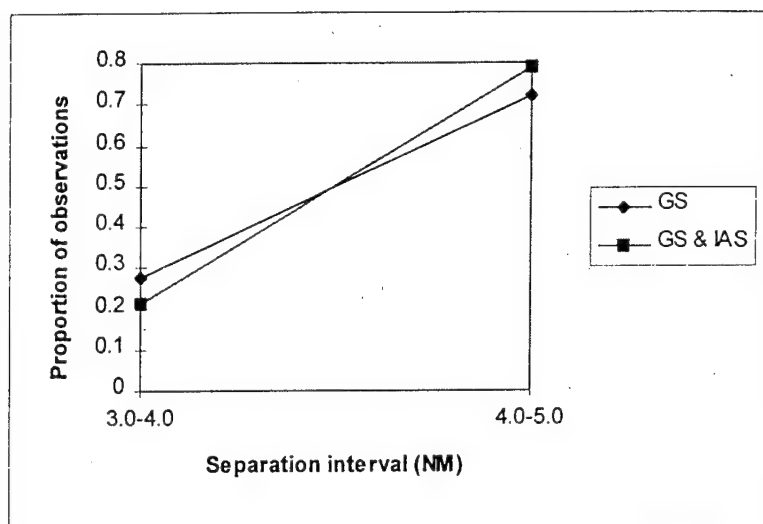


FIGURE 15. PROPORTION OF OBSERVATIONS UNDER SEPARATION INTERVAL (OPERATIONAL CONDITION 1, WIND 3, MANUAL MODE)

In summary, under wind condition 3, it was evident that the wind effects did not cause pilots to make the speed adjustments to maintain separation. Therefore, the provision of IAS information likely did not provide additional advantage for maintaining the required separation.

#### 4.4.2 Analysis of Separation Distributions for Operational Condition 2.

The results of the 2-way contingency table Chi-square tests for operational condition 2 are summarized in Table 11. The results of these tests indicated that the null hypothesis was not supported for all test combinations. Figures were again plotted for both speed information options in order to investigate the relationship between these proportions and the separation intervals.

##### 4.4.2.1 Wind Condition 1 (Headwind).

Figures 16 and 17 both indicate that more than adequate separation was maintained in wind condition 1. The minimum separation did not fall below the 3.0 to 4.0 NM range under the autopilot mode, and was within the 3.5 to 4.5 NM range when manually flying. Since the trailing aircraft was always experiencing higher head wind speeds than the leading aircraft, the wind did not provide the potential for separation violations. Therefore, the effect of wind on maintaining separation was the same whether or not IAS information was provided. Since there was no potential for violating the minimum separation due to winds, the provision of IAS information did not provide an additional advantage for maintaining the required separation.

TABLE 11. SUMMARY OF 2-WAY CONTINGENCY TABLE CHI-SQUARE TESTS  
(OPERATIONAL CONDITION 2)

| Wind Condition | Operating Condition | Control Mode | Result   |
|----------------|---------------------|--------------|--|
| 1              | 2                   | Autopilot    | Chi-square test statistic = 42.18<br>df = 1, $\alpha$ = 0.05<br>Chi-square reference value = 3.843<br>Result: Significant  |
| 1              | 2                   | Manual       | Chi-square test statistic = 64.82<br>df = 1, $\alpha$ = 0.05<br>Chi-square reference value = 3.843<br>Result: Significant  |
| 2              | 2                   | Autopilot    | Chi-square test statistic = 131.63<br>df = 2, $\alpha$ = 0.05<br>Chi-square reference value = 5.992<br>Result: Significant |
| 2              | 2                   | Manual       | Chi-square test statistic = 49.10<br>df = 2, $\alpha$ = 0.05<br>Chi-square reference value = 5.992<br>Result: Significant  |
| 3              | 2                   | Autopilot    | Chi-square test statistic = 162.79<br>df = 2, $\alpha$ = 0.05<br>Chi-square reference value = 5.992<br>Result: Significant |
| 3              | 2                   | Manual       | Chi-square test statistic = 7.374<br>df = 2, $\alpha$ = 0.05<br>Chi-square reference value = 5.992<br>Result: Significant  |

where - Chi-square test statistic is a computed value,  
df is the degrees of freedom,  
Chi-square reference value is based on the true Chi-square distribution for  
the corresponding degrees of freedom, and  
 $\alpha$  is the type I error probability.

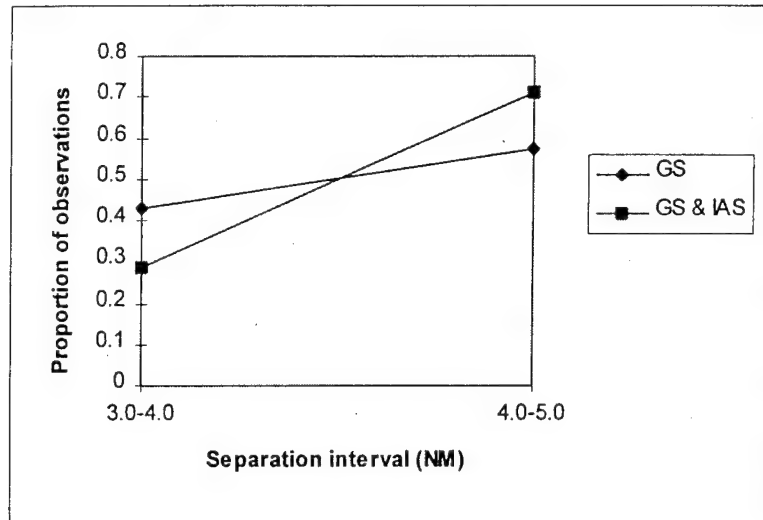


FIGURE 16. PROPORTION OF OBSERVATIONS UNDER SEPARATION INTERVAL (OPERATIONAL CONDITION 2, WIND 1, AUTOPILOT MODE)

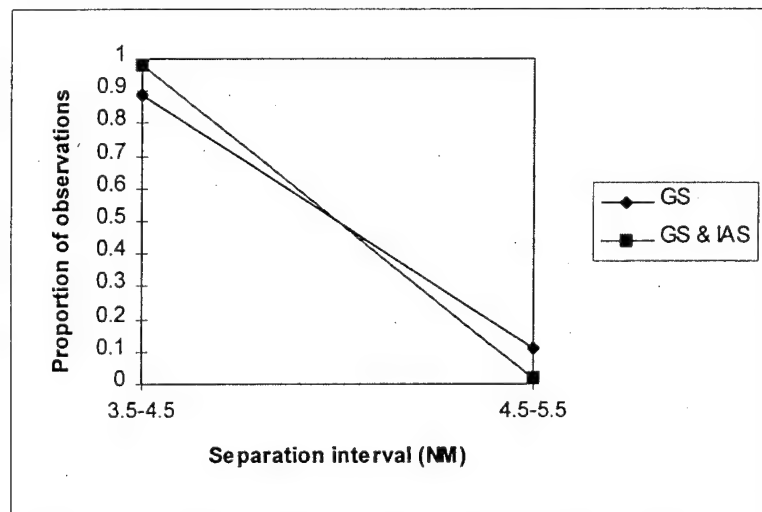


FIGURE 17. PROPORTION OF OBSERVATIONS UNDER SEPARATION INTERVAL (OPERATIONAL CONDITION 2, WIND 1, MANUAL MODE)

As in operational condition 1, however, when IAS was provided, pilots seemed to have slowed down earlier. This is observed by a higher proportion of observations under the 4.0-5.0 NM range as compared to when only GS was provided. This, again, may imply that pilots could plan their approach more cautiously with IAS information, creating the same positive outcome on relieving the domino effect. Unlike the previous finding, this phenomenon was present only when flying in the autopilot mode. Because manually flying the simulator was more difficult than flying in the autopilot mode, pilots may have concentrated on control activities.

#### 4.4.2.2 Wind Condition 2 (Wind Shear).

Figures 18 and 19 show the same trend for both the GS only and the GS and IAS options. Both figures indicate that, with IAS information available, a higher proportion of observations occur in the 3.5 to 4.5 NM separation range.

This result is noteworthy. It is likely that the pilots of the trailing aircraft used IAS information to determine the winds that were affecting the leading aircraft. Realizing that the winds at lower altitudes were changing from a tail wind to a head wind while they were still experiencing a tail wind, the pilots anticipated closing on the leading aircraft in the near term and made the necessary speed corrections to reduce the closure rate. These early adjustments enabled the trailing aircraft to maintain a separation interval in the 3.5 to 4.5 NM range.

Conversely, under the GS-only option, the pilots of the trailing aircraft did not detect the wind change until later in the approach, and hence, speed corrections were made at a later stage. A higher proportion of observations, therefore, fell within the 2.5 to 3.5 NM separation interval.

As noted in section 4.1 and section 4.2, wind condition 2 produced both separation violations and missed approaches. But, in general, provision of IAS information seemed to help the pilots to sustain a higher separation interval, as they were able to identify changes in the wind direction and to anticipate the closure potential.

#### 4.4.2.3 Wind Condition 3 (Strong Headwind).

Figures 20 and 21 exhibit the same trends under both display options. A strong head wind component affected both aircraft. As the aircraft descended, the wind speed decreased, thus increasing the separation. Throughout the approach, the wind affecting the trailing aircraft was always more than that affecting the leading aircraft. Since there was always more than adequate separation present, the presentation of IAS information likely did not affect pilot speed control behavior. They apparently were able to determine that adequate separation would exist throughout the flight. A minimum separation interval in the range of 3.0 to 4.0 NM was achieved in both manual and autopilot modes. Under wind condition 3, the wind did not create a potential for violation of separation, and therefore, the presentation of IAS apparently did not provide an additional advantage for maintaining the required separation. This result is similar to that found in operational condition 1, wind condition 3.

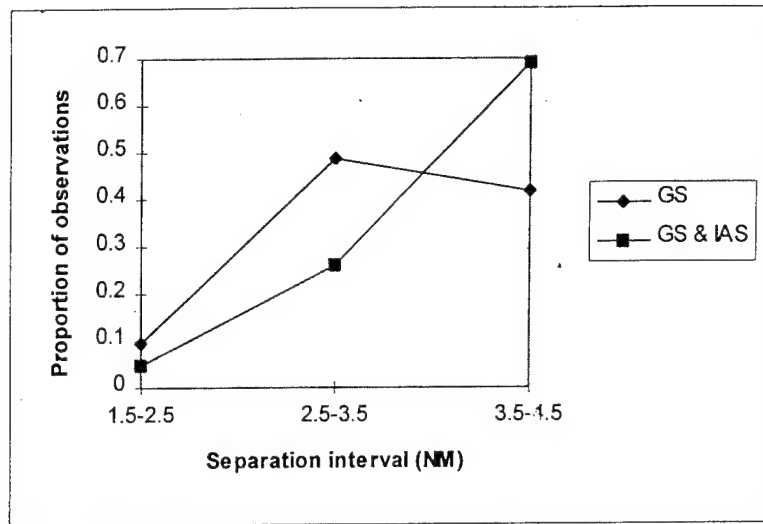


FIGURE 18. PROPORTION OF OBSERVATIONS UNDER SEPARATION INTERVAL (OPERATIONAL CONDITION 2, WIND 2, AUTOPILOT MODE)

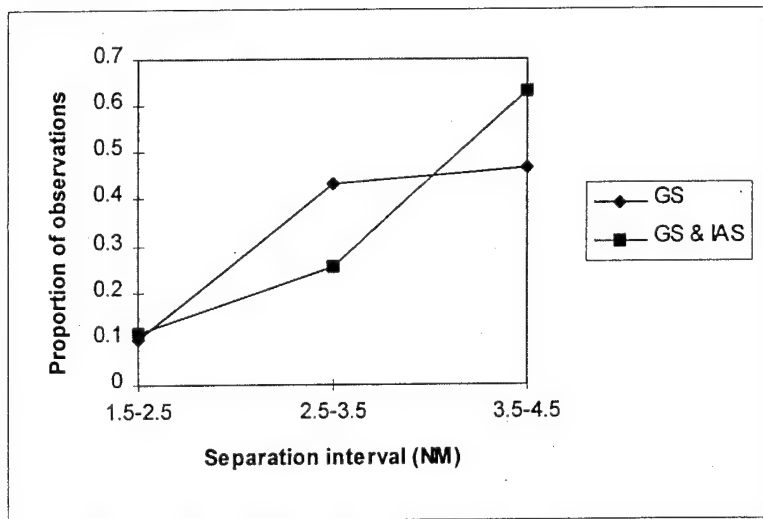


FIGURE 19. PROPORTION OF OBSERVATIONS UNDER SEPARATION INTERVAL (OPERATIONAL CONDITION 2, WIND 2, MANUAL MODE)



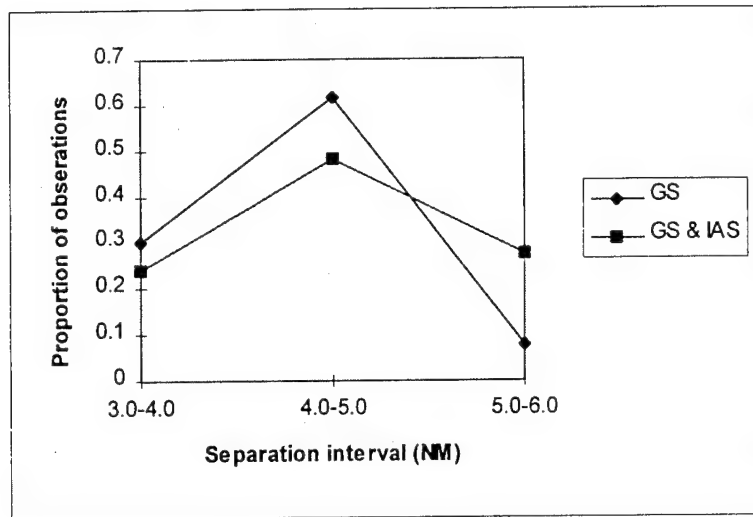


FIGURE 20. PROPORTION OF OBSERVATIONS UNDER SEPARATION INTERVAL (OPERATIONAL CONDITION 2, WIND 3, AUTOPILOT MODE)

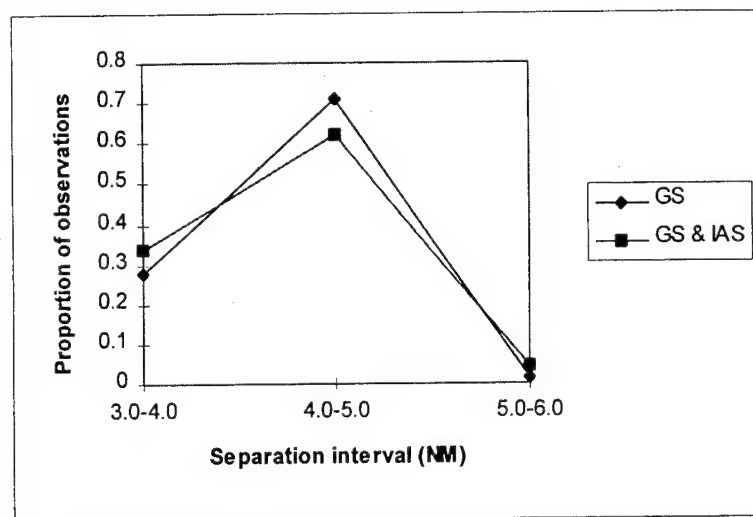


FIGURE 21. PROPORTION OF OBSERVATIONS UNDER SEPARATION INTERVAL (OPERATIONAL CONDITION 2, WIND 3, MANUAL MODE)

#### 4.5 QUESTIONNAIRE ANALYSIS.

A questionnaire was administered at the end of each run and another at the completion of all runs flown by each crew. The End of Run Questionnaire focused on information specific to each run and was completed by the observer and the pilots. This questionnaire identified whether or not the approach was completed, missed approaches or violations that may have occurred, and problems the pilots may have encountered during the approach. An analysis was not performed on the End of Run Questionnaire responses. A sample questionnaire is provided in Appendix B.

An End of Simulation Questionnaire was also distributed to each pilot at the end of all 24 planned runs. The questions, the pilot's responses, and (where appropriate) the statistical tests that were performed are described in the following sections.

#### 4.5.1 Question 1 Results.

Question 1 stated: "What kind of speed information would you prefer to be presented to maintain the desired separation on final approach?"

Responses to Question 1 were grouped into "GS Only" and "Some Preference for IAS" categories for analysis. The number of responses in each category was:

|                         |   |
|-------------------------|---|
| GS Only                 | 2 |
| Some Preference for IAS | 8 |

Selection of any one of the following answers by a subject was considered to fall within the "Some Preference for IAS" category:

| <u>Possible Answers</u> | <u>Number Selected</u> |
|-------------------------|------------------------|
| Both GS and IAS         | 6                      |
| Either GS or IAS        | 1                      |
| GS and Toggle for IAS   | 1                      |

In this case, the null hypothesis was: The proportion of responses favoring "Some Preference for IAS" is equal to the proportion of responses favoring "GS only." The alternate hypothesis was: The proportion of responses favoring "Some Preference for IAS" is higher than the proportion of responses favoring "GS Only."

Based on the Binomial distribution, the probability of obtaining 8 responses out of a sample size of 10 is 0.012 (one tailed test). This probability is lower than the type I error probability ( $\alpha = 0.05$ ). Therefore, the null hypothesis is rejected.

This result implies that the proportion of subjects who favored "Some Preference for IAS" is significantly higher than the proportion of subjects who favored "GS Only."

#### 4.5.2 Question 2 Results.

Question 2 stated: "Did you use the IAS information when it was presented?"

| <u>Possible Answers</u> | <u>Number Selected</u> |
|-------------------------|------------------------|
| Yes                     | 8                      |
| No                      | 2                      |

In this case, the null hypothesis was: A "Yes" response is equally likely as a "No" response. The alternate hypothesis was: A "Yes" response is more likely than a "No" response.

Based on the Binomial distribution, the probability of obtaining 8 responses out of a sample size of 10 is 0.012 (one tailed test). This probability is lower than the type I error probability ( $\alpha = 0.05$ ).

Therefore, the null hypothesis is rejected.

This result implies that the proportion of subjects who chose a "Yes" response is significantly higher than the proportion of those who chose a "No" response. The remaining questionnaire responses and pilot comments are provided in Appendix C.

#### 4.6 COMMENTS FROM THE DEBRIEFING SESSIONS.

A debriefing session was conducted at the end of each day to elicit information on various topics related to the simulation. Discussions were held regarding the use of IAS, the workload encountered, the realism of the winds that were used, crew coordination issues, pilot preferences, and the fidelity of the simulator that was used. These comments are synopsized in Appendix D.

The following sections summarize the discussions that occurred during the debriefing sessions.

##### 4.6.1 IAS Preferences.

The comments regarding IAS generally amplify those contained in the End of Simulation Questionnaire. Overall, 10 comments favored the utility of IAS, 3 were neutral, and 2 did not favor use of IAS.<sup>1</sup> These comments are synopsized in Table D-1 in Appendix D.

##### 4.6.2 Effect Of Display Information On Workload.

In general, four comments indicated that workload level was acceptable and four were ambivalent. None of the pilots indicated that the workload level was unacceptable or excessive. These comments are synopsized in Table D-2 in Appendix D.

##### 4.6.3 Wind Realism.

Pilot opinions differed as to whether the winds were realistic. Some pilots had experienced similar winds at Hong Kong and Kennedy airports. Some pilots felt that these winds, although possible, were not frequent. These comments are synopsized in Table D-3 in Appendix D.

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<sup>1</sup> More than one comment was made by some pilots.

#### 4.6.4 Display Related Issues.

The following list summarizes the responses to the question: "How else can we present the information on the display?"

- a. The type of aircraft is helpful on the display.
- b. The call sign is helpful because otherwise you couldn't remember it.
- c. Display information was perfect.
- d. The display was satisfactory.
- e. Provide the ability to get rid of information the pilot does not want to see.
- f. Move information to the right of the dot [fix name] so it is not covered.
- g. Aircraft type and call sign are not needed.
- h. Callsign may be beneficial [to present].
- i. IAS clutters the screen.
- j. Like the arc, but don't like it when screen is cluttered.
- k. Less information would be better.

Pilot preference towards manual or autopilot mode and general issues are indicated in Appendix D.

### 5. DISCUSSION.

The objectives of this study were to investigate whether IAS information is necessary for maintaining separation, and whether IAS information provides wind shear information. The results of this study should be considered as indicative, and not conclusive, for the following reasons:

- a. A sample size of 10 is statistically small.
- b. Due to time constraints, the wind conditions used were extremes.

#### 5.1 UTILITY OF IAS FOR MAINTAINING SEPARATION.

Statistically, the average separation was not significantly different for all 12 test combinations, under both display options. This clearly indicates that IAS information is not required to maintain separation. This finding is confirmed by the fact that, except under wind shear conditions, the number of missed approaches and the frequency of separation violations were zero under both display options.

During the debriefing sessions, the pilots indicated that, to maintain separation, they looked at their present separation (distance between the two aircraft), the GS of both aircraft, and the range information (distance from the runway). Based on this information, they made an instantaneous decision whether or not they needed to change their speed. This explanation supports the statistical findings stated in the above paragraph.

## 5.2 UTILITY OF IAS FOR IDENTIFICATION OF WIND SHEAR.

In scenarios starting at operational condition 1 (with both aircraft starting at 1800 ft), the pilots seemed to be able to anticipate wind changes and (with the necessary mental calculations) seemed to be able to predict that separation would not be violated. Under the GS only condition, it appeared that pilots needed to make more speed corrections to maintain the desired separation. This is observed in Figures 12 and 13.

In scenarios starting at operational condition 2 (with the leading aircraft starting at 1800 ft and the trailing aircraft starting at 4000 ft), when both the GS and IAS of the leading aircraft were provided, the pilots appear to have anticipated that they might close due to wind changes and, therefore, made the necessary speed corrections early enough to avoid the loss of separation. This is observed in Figures 18 and 19 where a higher proportion of observations lie in the larger separation interval when IAS was provided.

Both of these findings are validated by the End of Simulation Questionnaires, which indicate that a significantly higher proportion of pilots favored the depiction responses of IAS information as some option. The questionnaires also indicate that a significantly higher proportion of pilots used IAS information. This finding is further validated by comments made by pilots during debriefing sessions, suggesting that IAS information is useful in identifying wind changes and planning for speed adjustments.

## 6. CONCLUSIONS.

Indicated Airspeed (IAS) seems to help pilots as a planning tool for predicting the winds and, thereby, anticipating the potential loss of separation. The availability of IAS enables them to make the necessary speed changes early in the approach. Use of IAS was particularly advantageous in situations when wind shear was the apparent factor that caused the separation loss potential.

However, IAS did not appear to provide any additional advantage for maintaining an instantaneous separation, implying that Ground Speed (GS) only is sufficient for maintaining the separation.

Therefore, if the objective is to maintain separation, then the presentation of GS is sufficient. If the objective is to identify wind shear, then IAS information is required.

These conclusions are based on the results of paired t-tests and Chi-square tests, subjective questionnaire responses, and debriefing comments.

## 7. RECOMMENDATIONS.

Based on pilot comments, questionnaire responses, and debriefing session discussions, the following recommendations are made for future research.

## 7.1 WORKLOAD, SCAN, COORDINATION, AND RESOURCE MANAGEMENT.

During the debriefing sessions, most pilots responded that the workload involved in the Approach Station Keeping (ASK) activity was acceptable. However, this study was specifically designed to obtain information regarding the use of IAS on final approach. Time constraints did not permit the collection of data to support objective analysis of pilot workload and scan patterns, crew coordination procedures, or cockpit resource management issues.

It is recommended that such issues be thoroughly investigated, through simulation, prior to implementing Automatic Dependent Surveillance - Broadcast (ADS-B) in a station keeping application.

## 7.2 PRESENTATION METHODS.

For this simulation, a Navigation Display was used to provide the information needed for station keeping. This approach was selected due to the availability of an easily modified Navigation Display installed in a simulator that could also be adapted to accomplish the study objectives. This solution, while practical due to time constraints, is not necessarily the optimum device to present the information, or, if optimum, the computer-human interface may not be optimal. As indicated in Appendices C and D, alternative options were noted in the questionnaire responses and discussed during the debriefing sessions.

It is recommended that other options be explored, through simulation, to define an optimally efficient, effective, and user-friendly presentation technique.

## 7.3 EXPANDED SCOPE.

This study considered only a single instrument approach and was constrained by distance, altitude, wind factors, and number of aircraft. In the debriefing sessions, pilots observed that the station keeping technique may be even more beneficial if applied in situations that occur farther from the airport. However, they also alluded to a potential domino effect whereby speed adjustments could be magnified as aircraft farther from the airport attempt to accommodate changes made by aircraft ahead of them in the landing stream.

It is recommended that additional research be conducted, through simulation, to determine situations where ADS-B technology would offer an operational advantage in managing air traffic. Such studies should encompass a broad spectrum of wind conditions, traffic loads, and operational conditions.

## REFERENCES

Initial SAS applications selected for concept validation (1995-96). (1995). Unpublished manuscript.

Kirkman D. and Peed, D. (1995). Summary of application information needs - preliminary input (RTCA SC-186 Automatic Dependent Surveillance Broadcast (ADS-B) Working Group 1). Unpublished manuscript.

Livack, G. S. (1995a). Defining ADS-B for SAS in the context of a free flight environment. SAS Working Draft. Unpublished manuscript.

Livack, G.S. (1995b). An IFR installed cockpit "work station" for general aviation use. Unpublished manuscript.

## GLOSSARY

Airspeed - The speed of an aircraft relative to its surrounding air mass. Commonly used airspeed terms include Calibrated Airspeed (CAS), Equivalent Airspeed (EAS), Ground Speed (GS), Indicated Airspeed (IAS), and True Airspeed (TAS).

Automatic Dependent Surveillance (ADS) - An emerging technology in which aircraft automatically transmit, via a satellite data link, information derived from on-board navigation systems. As a minimum, the data include three dimensional position and time. Additional data may be provided, as appropriate.

Automatic Dependent Surveillance - Broadcast (ADS-B) - An emerging technology that exploits the capabilities of ADS to periodically broadcast aircraft identification, position, intent, and environmental information to other aircraft and to ground users. Among the intended applications are: Cockpit Display of Traffic Information (CDTI), aircraft-based collision avoidance, aircraft-based conflict detection, aircraft-based conflict resolution, aircraft exchange of Pilot Reports (PIREPS), aircraft exchange of emergency status, domestic ground surveillance, and ATC conformance monitoring.

Calibrated Airspeed (CAS) - Indicated airspeed corrected for installation error.

Equivalent Airspeed (EAS) - Calibrated airspeed corrected for compressibility effect.

Ground Speed (GS) - True airspeed corrected for wind. The speed of an aircraft relative to the surface of the earth.

Indicated Airspeed (IAS) - The airspeed displayed by the airspeed indicator. This airspeed is uncorrected for all errors associated with airspeed measurement.

Situational Awareness for Safety (SAS) - The term used to describe an FAA initiative currently in the concept development phase. The concept envisions amalgamation of a number of existing and emerging technologies to establish a robust, integrated space-, airborne-, and ground-based future Air Traffic Management System.

Traffic Alert and Collision Avoidance System (TCAS) - An independent airborne collision avoidance capability. TCAS I provides traffic advisories to assist pilots in locating potential midair collision threats. TCAS II provides traffic advisories and vertical-plane resolution advisories that indicate the direction the aircraft should maneuver to avoid collisions. TCAS IV, currently evolving, will provide traffic advisories and vertical and horizontal resolution advisories.

True Airspeed (TAS) - Equivalent airspeed corrected for air density.



## ACRONYMS

|       |   |
|-------|---|
| ADS-B | Automatic Dependent Surveillance                  |
| ALPA  | Airline Pilots Association                        |
| APA   | Allied Pilots Association                         |
| ASK   | Approach Station Keeping                          |
| ATC   | Air Traffic Control                               |
| CDTI  | Cockpit Display of Traffic Information            |
| DAL   | Delta Airlines                                    |
| DEN   | Stapleton International Airport                   |
| EWR   | Newark International Airport                      |
| FAA   | Federal Aviation Administration                   |
| FSS   | Flight Service Station                            |
| ft    | feet  |
| GA    | General Aviation                                  |
| GAT   | General Aviation Trainer                          |
| GPS   | Global Positioning System                         |
| GS    | Ground Speed                                      |
| IAS   | Indicated Airspeed                                |
| ILS   | Instrument Landing System                         |
| JFK   | John F. Kennedy International Airport             |
| KIWI  | KIWI International Airline                        |
| KT    | Knot  |
| LAX   | Los Angeles International Airport                 |
| LGA   | La Guardia Airport                                |
| MASPS | Minimum Aviation System Performance Standard      |
| MSL   | Mean Sea Level                                    |
| NATCO | Northwest Airlines Training Corporation           |
| NM    | Nautical Mile(s)                                  |
| NOTAM | Notice to Airman                                  |
| ORD   | Chicago O'Hare International Airport              |
| PF    | Pilot Flying                                      |
| PIREP | Pilot Report                                      |
| PNF   | Pilot Not Flying                                  |
| RCS   | Reconfigurable Cockpit Simulator                  |
| RDHFL | Research Development and Human Factors Laboratory |
| RDU   | Raleigh-Durham International Airport              |
| SA    | Situational Awareness                             |
| SAS   | Situational Awareness for Safety                  |
| SEA   | Seattle-Tacoma International Airport              |
| SFO   | San Francisco International Airport               |
| T&A   | Technical and Administration                      |
| TCAS  | Traffic Alert and Collision Avoidance System      |

UPS  
WG

United Parcel Service  
Working Group

## APPENDIX A

### PILOT BRIEFING AND TRAINING HANDOUT

You are participating in a test which may result in the development of new cockpit equipment and procedures to enable pilots to maintain their own in-trail spacing between aircraft flying IMC approaches to the same runway.

You will be operating a medium-fidelity B747-400 simulator and making ILS approaches to Runway 23L at the Raleigh-Durham (RDU) airport. The Decision Height (DH) at RDU is 200 feet AGL. The RDU VOR/DME is located 0.4 NM south of the Runway 23L threshold. The weather is assumed to be IMC. Your aircraft will be following a commuter aircraft, referred to as the GAT (General Aviation Trainer). The GAT will emulate a BE-20, callsign N432B. Both aircraft will be on the final approach course at the start of the problem. The problem will terminate when the commuter crosses the landing threshold or when you choose to make a missed approach. The missed approach procedure is: FLY RUNWAY HEADING, CLIMB AND MAINTAIN 3000.

Your role is to fly the B747-400 simulator so as to maintain **NOT LESS THAN 3 NM** separation between your aircraft and the commuter **WHEN YOUR AIRCRAFT IS 10 NM OR MORE FROM THE AIRPORT** and **NOT LESS THAN 2.5 NM** separation between your aircraft and the commuter **WHEN YOUR AIRCRAFT IS LESS THAN 10 NM FROM THE AIRPORT**. To ensure that the data is representative of that which would be found were you flying an operational aircraft, we ask that you do not employ unrealistic piloting techniques to maintain station (e.g., lowering and then raising the landing gear).

Because the test does not include ATC, you should assume that you have been cleared for the approach and that a landing clearance would be issued at the appropriate time. You should also assume that all aircraft systems are operating normally.

The B747-400 Navigational Display has been modified to enable presentation of a three mile range ring segment and a data tag for the commuter aircraft. During the test, the data tag will display GS or GS and IAS, as well as aircraft callsign and type. Emulated TCAS II technology is also incorporated in the simulator and is used to present the position information for the commuter. TCAS II color coding is used, however, aural alarms will not be provided.

The test encompasses two basic scenarios that are flown under three different wind conditions. The conditions used for each run (approach) will vary in starting position, wind condition, and the speed information that is provided for the commuter. You will be informed of the wind at your altitude and on the surface at the start of each run.

You will be asked to both hand fly the approaches and to fly the approaches using autopilot. Each pilot will fly 12 runs over the two day period as Pilot Flying and 12 runs as Pilot Not Flying. We ask you to occupy the left seat when operating as the Pilot Flying.

## INFORMATION REGARDING THE SIMULATOR

---

### V-REF

CHECK GROSS WEIGHT ON REFERENCE PAGE TO CONFIRM V-REF FOR LANDING FLAP SETTING SELECTED

---

### SUGGESTED FLAP SETTINGS

200 KNOTS - FLAPS 5

180 KNOTS - FLAPS 10

160 KNOTS - FLAPS 20

V-REF + 5 FINAL, FINAL APPROACH, GEAR DOWN - FLAPS 20 OR 25

---

### ATTITUDE AND THRUST SETTINGS

LEVEL FLIGHT, 200 KNOTS, FLAPS 5, GEAR UP      7 DEGREES NOSE UP - 1.18 EPR

LEVEL FLIGHT, 180 KNOTS, FLAPS 10, GEAR UP      9 DEGREES NOSE UP - 1.22 EPR

ON GLIDE SLOPE APPROACHING FAF,

LANDING FLAPS 20 OR 25 GEAR DOWN      8 DEGREES NOSE UP - 1.22 EPR

---

### STABILIZER TRIM

STABILIZER TRIM MAY NOT FEEL REALISTIC NOR PROVIDE A LINEAR RESPONSE  
- SUGGEST USE OF ATTITUDE TARGETS TO CROSS CHECK FD/AP COMMANDS

---

### SUGGESTED SETUP FOR FD/AP CONTROL PANEL

(LEFT TO RIGHT)

1. A/T ARM TOGGLE SWITCH -- UP -- 200 OR 180 SELECTED IN SPEED WINDOW
  2. 230 SELECTED IN HEADING WINDOW -- AUTO BANK ANGLE SELECTED
  3. HEADING HOLD LIGHT ILLUMINATED -- VERTICAL SPEED WINDOW READS 0
  4. ALTITUDE SELECTED TO 1800 OR 4000 WITH ALTITUDE HOLD LIGHT ON
  5. APPROACH FUNCTION ANNUNCIATION ILLUMINATED WITH "LOC" DISPLAYED AT THE TOP CENTER OF EADI WITH AT LEAST ONE A/P IN COMMAND MODE
  6. BOTH FLIGHT DIRECTOR SWITCHES SELECTED ON
- 

### OUT OF THE WINDOW VIEW

WHEN YOU BREAKOUT, THE RUNWAY WILL BE VISIBLE ON THE CRT ABOVE THE GLARE SHIELD.

---

APPENDIX B  
QUESTIONNAIRES

## APPROACH STATION KEEPING EXPERIMENT

### PILOT BACKGROUND QUESTIONNAIRE

The following requested information will be kept confidential. Personal information will not be released in the documents or reports that will be produced as a result of this study. When necessary, individuals will be identified as Subject A, Subject B, etc.

Date: \_\_\_\_\_

Name: \_\_\_\_\_

Address: \_\_\_\_\_

Telephone: \_\_\_\_\_ Fax No.: \_\_\_\_\_

Age: \_\_\_\_\_ Gender: \_\_\_\_\_

1. How many combined hours of experience do you have as a pilot of civilian and military aircraft? \_\_\_\_\_
2. How many hours of experience do you have as a pilot engaged in Part 121 operations? \_\_\_\_\_
3. Are you currently active as a Part 121 pilot (circle one)? YES NO  
If NO, when were you last active? \_\_\_\_\_
4. How many hours of experience do you have as a pilot in glass cockpit equipped aircraft? \_\_\_\_\_
5. What glass cockpit type ratings do you hold?  
\_\_\_\_\_

## APPROACH STATION KEEPING EXPERIMENT

### END OF RUN QUESTIONNAIRE

Name: \_\_\_\_\_

Date: \_\_\_\_\_

Run: \_\_\_\_\_

- 
- 
1. Did you complete the approach (circle one)?      YES    NO

If NO, please identify the reasons(s).

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2. Did you encounter any problems in maintaining the desired separation (circle one)?      YES    NO

If YES, please describe the problem(s).

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3. Would additional information have aided you in maintaining the necessary separation (circle one)?      YES    NO

If YES, please identify the information.

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4. Please provide any other comments, questions, or concerns that you may have regarding this run.

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## APPROACH STATION KEEPING EXPERIMENT

### END OF SIMULATION QUESTIONNAIRE

Name: \_\_\_\_\_

Date: \_\_\_\_\_

1. What kind of speed information would you prefer to be presented to maintain the desired separation on final approach (circle one)?
- a. GS only
  - b. IAS only
  - c. Both GS and IAS
  - d. Either GS or IAS
  - e. GS and Toggle for IAS
  - f. IAS and Toggle for GS
  - g. Other (explain below)

2. Did you use the IAS information when it was presented (circle one)? YES NO

If YES, please explain how it was used.

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If NO, please indicate why you did not use the IAS information (circle one).

- a. Lack of time
- b. Difficult to interpret
- c. Both a. and b., above
- d. Other (please explain)

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3. How realistic were the scenarios? Please discuss in terms of wind conditions, altitudes, and speeds.

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**END OF SIMULATION QUESTIONNAIRE**  
**(Continued)**

4. Should additional information be provided on the Navigation Display to assist in maintaining the desired separation (circle one)?                      YES    NO

If YES, please identify the information desired.

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5. If you think additional information is needed, how and where would you prefer it to be presented?

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6. In your opinion, would station keeping as exercised in this simulation be operationally practical? Please discuss. Consider procedures, equipment, training, and the manner in which information was displayed.

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7. Was the Reconfigurable Cockpit Simulator (RCS) adequate to accomplish the objectives of this experiment (circle one)?                      YES    NO

If NO, what improvements do you recommend?

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8. Please provide any other comments, questions, or concerns that you may have regarding this experiment.

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## APPROACH STATION KEEPING EXPERIMENT

### OBSERVER QUESTIONNAIRE

Name: \_\_\_\_\_

Date: \_\_\_\_\_

Run: \_\_\_\_\_

1. Please circle the number of times the separation was violated during the run.

0      1      2      3      4      5      6      7      8      9      10 or more

2. Did the pilot "go around" to avoid a separation violation (circle one)?

YES   NO

Please describe the "go around" procedure that was used.

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3. In your opinion, was the information presented adequate for *this* pilot to maintain the necessary separation (circle one)?      YES   NO

If NO, please describe the reason(s).

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## APPROACH STATION KEEPING EXPERIMENT

### GENERAL AVIATION TRAINER (GAT) PILOT LOG

Name: \_\_\_\_\_

Date: \_\_\_\_\_

Run: \_\_\_\_\_

1. Was the run successfully completed (circle one)?

YES NO

If NO, describe why it was not successful.

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## APPENDIX C

### END OF SIMULATION QUESTIONNAIRE RESPONSES

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Question 1: What kind of speed information would you prefer to be presented to maintain the desired separation on final approach?

- |    |                       |   |
|----|-----------------------|---|
| a. | GS only               | 2 |
| b. | IAS only              | 0 |
| c. | Both GS and IAS       | 6 |
| d. | Either GS or IAS      | 1 |
| e. | GS and Toggle for IAS | 1 |
| f. | IAS and Toggle for GS | 0 |
| g. | Other                 | 0 |

One pilot commented that he would like the ability to declutter both [display options] in [a] high density environment.

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Question 2: Did you use the IAS information when it was presented?

|     |   |
|-----|---|
| Yes | 8 |
| No  | 2 |

If YES, please explain how it was used.

Pilots commented as follows:

- Plan protected control of separation
- For [identification of] wind speed and/or [wind] shear
- To compare airspeed of us [and] them
- To compute wind at his/her altitude
- Cross check against my IAS
- As a reference starting point for our target IAS
- More so [useful] when further from the airport
- You were better able to determine when an [leading] aircraft was slowing

If NO, please indicate why you did not use the IAS information,

- |    |                        |   |
|----|------------------------|---|
| a. | Lack of time           | 0 |
| b. | Difficult to interpret | 0 |
| c. | Both a. and b.         | 0 |
| d. | Other                  | 1 |

One pilot commented that GS seems to be simpler to apply to the situation.

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Question 3: How realistic were the scenarios? Please discuss in terms of wind conditions, altitudes, and speeds.

Pilots commented as follows:

- Wind unrealistic, all else logical
- OK
- Very realistic - GSs coordinate with wind indications
- 50 [knots] tail [wind] to 30 [knots] head [wind] [is] unusual, but possible
- Altitude and speeds were realistic, wind conditions were not
- It is very unlikely you would see 70 knots tail winds at 1800' - 4000'. Maybe once every several years do you see unusual winds of this sort
- They were realistic worst case winds. However, to be truly realistic changing cross winds gusts would be incorporated.
- The high speed at 4000 ft seemed to be slightly unrealistic since it is barely seen in real time
- Most scenarios were good. No need to repeat so many. Could have used some cross winds
- Altitudes were good. In my experience I've found that smaller a/c [aircraft] would have a slower g/s [ground speed]. More wind scenarios would add more of a challenge

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Question 4: Should additional information be provided on the Navigational Display to assist in maintaining the desired separation (circle one)?    YES    NO

Yes    4  
No    6

If YES, please identify the information desired.

Pilots commented, as follows:

- May be a trend arrow if closure is excessive
  - Closing or opening trend indicator would speed up interpreting situations. Put it on the other side so it doesn't interfere with displayed information
  - If you could display the separation distance so you could determine closure and separation
- 
-

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Question 5: If you think additional information is needed, how and where would you prefer it to be presented?

Pilots commented, as follows:

- Red [color of closure rate arrow] if close [and] green when [closure rate is] OK.
- [Move data block] to the right [side] of the [fix] symbol.
- No need for a/c [aircraft] type. Just need call sign and [whether aircraft type is] heavy or not.

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Question 6: In your opinion, would station keeping, as exercised in this simulation, be operationally practical? Please discuss. Consider procedures, equipment, training, and the manner in which information was displayed.

Pilots commented as follows:

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Question 7: Was the Reconfigurable Cockpit Simulator (RCS) adequate to accomplish the objectives of this experiment?

|     |    |
|-----|----|
| Yes | 10 |
| No  | 0  |

If NO, what improvements do you recommend?

Pilots commented as follows:

- Barely - but seemed to do what was needed - as with most simulators was not user friendly.
  - Controls stiff and flight director too sensitive.
- 
-

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Question 8: Please provide any other comments, questions, or concerns that you may have regarding this experiment.

Pilot comments were as follows:

- Practical approach.
- For what our objective was I feel it was accomplished and I feel this would be good adjunct to our auto flight system.
- All OK - good simulation.
- Some manual approaches use auto throttle while manual flying.
- Remove airplane call sign and type from display. Move altitude from 12 o'clock position to an area less congested.
- Aircraft ID [call sign] is not needed.

# **APPENDIX D** **DEBRIEFING SESSION DISCUSSIONS**

Table D-1 categorizes the pilot's responses to the question, "What is your opinion about IAS information?"

**Table D-1 IAS information Opinions**

| Positive  | Neutral  | Negative   |
|---|--|--|
| GS is looked at first, but IAS is helpful                                       | GS was sufficient, but it was nice to have IAS                 | IAS is more clutter                                      |
| GS and IAS are both needed to pick up trends                                    | GS is the primary source, it is a must for separation          | IAS is not necessary, separation is ATC's responsibility |
| They thought they wouldn't use IAS, but they did. They liked IAS                | IAS is useful, but it gets to the point of diminishing returns |  |
| IAS is a planning tool  |  |  |
| Only one A/S [airspeed] needed, not both (either one)                           |  |  |
| Both pilots used IAS  |  |  |
| IAS would be more useful further from the airport. Pilots would use both speeds |  |  |
| Good to have both, without IAS and GS pilot would ask ATC                       |  |  |
| One or the other isn't enough; you need both to determine a trend               |  |  |



Table D-2 summarizes the pilot's responses to the question "Is the workload acceptable with this display information?"

**Table D-2 Workload Acceptability**

| Acceptable  | Ambivalent   |
|---|--|
| Workload not increased by addition of IAS, and decreased after pilots adjusted to scanning data and knowing where to look | Workload increased initially, but decreased with use |
| Workload was OK   | PNF workload will be higher than PF workload         |
| Workload was acceptable   | The same approach over and over becomes very simple  |
| Workload decreased with use of IAS and GS   | Manual flight has higher workload [than autopilot]   |

Table D-3 categorizes the responses to the question, "Were the winds realistic?"

**Table D-3 Wind Realism**

| Realistic   | Neutral   | Unrealistic                        |
|---|---|------------------------------------|
| The wind in the Simulation was similar to flying into a microburst, and procedures for that situation are very conservative | If wind shear in the real world was like the wind in the Simulation, they wouldn't have made it | Winds were unrealistic             |
| Such winds are experienced at JFK due to three runway configuration   | Winds are unrealistic; they are rare cases  | Cross winds could add more realism |
| Such winds are experienced at Hong Kong   |   |                                    |
| Simulation was pretty realistic   |   |                                    |

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The following list summarizes the pilot's responses to the question, "Would you prefer to fly in autopilot or manual mode under these kinds of winds?"

- There was a difference between hand flying and autopilot, but [I] prefer autopilot
- Manual flight if workload is high
- Prefer manual flying, but it was easier when autopilot was on
- Would mostly use autopilot

=====

The following list summarizes the pilot's responses to the question, "Do you have any other comments?"

- This [station keeping with ADS-B] would be important for more than two aircraft. If the computer can provide information so you can determine the effect on planes following you when you slow down to keep separation from the plane in front of you
  - This [station keeping with ADS-B] would be very helpful unless you were going into a high density airport where an aircraft is slowing too much; then it would affect too many other following aircraft
  - This [station keeping with ADS-B] would be helpful if everybody has the boxes in their aircraft
- =====